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Feasibility of Pervious Concrete Pavement: A Case Study of Karanjade Node, Panvel

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Abstract

The construction industry needs innovative ideas to manage the increasing rate of impervious surfaces. Pervious concrete allows water to pass directly through it, decreases the free runoff, and allows groundwater to recharge. This research study intends to find the feasibility of pervious concrete as a pavement at Karanjade in Panvel, India. Examination of five-year rainfall data helped calculate the quantity of precipitation occurring in this area above 1000mm. Traffic volume study determined low traffic roads during peak hours, which was 378.156 PCU/Hr. Pervious concrete pavement for low traffic volume road was designed as per IRC SP 62: 2014. Slab with a thickness of 200mmwasdesigned and checked for edge and corner stresses.

Keywords - *Pavement Design, PCU, Pervious Concrete, Rainfall Analysis, Traffic Volume Study*

I. INTRODUCTION

Increasing urbanization gradually leads to overload on the drainage system with the frequent flow of polluted water and uncontrolled flooding. Upgrading or redesigning the existing system is not an effective solution for this issue. Hence, it is necessary to develop strategies to reduce runoff before it gushes into the drainage system [1]. Pervious concrete pavement is increasingly used to reduce the amount of runoff water. It is a pioneering material, a mixture of cement, water, coarse aggregate, little to no fine aggregate, and admixture. The absence of the fine aggregates leads to void networks, allowing water to pass through them [2]. Thus pervious pavement system allows the runoff water to infiltrate through it and replenish groundwater. Pervious concrete is useful for various other applications, but it is primarily used is in pavements. Due to its reduced Strength related to high porosity, it cannot be used in highway pavement. It can still have application in vehicle parking areas, pathways, driveways, sidewalks, alleys, and low volume roads. It also serves environment-friendly benefits such as stormwater reduction, groundwater recharge, pollutant dwindling, reduces river peak flow, heat island reduction, noise reduction, and skid Reduction. With the proper addition of chemical admixture, water-cement ratios between 0.27 and 0.30 perfect mixtures are obtained. Slump values achieved are usually less than 20 mm. Depending upon the compaction method adopted, the porosity range may vary from 15 to 30%. Pervious concrete is also called gap-graded concrete, permeable concrete, and no-fines concrete. For sustainable development, pervious concrete is an important application [3].

II. LITERATURE REVIEW

An innovative model of pervious pavement was put forward, and experiments were carried out for various proportions of trial mixes to match the M20 grade of concrete. The components used for the experiment were water-cement ratio, coarse aggregate, and cement to the coarse aggregate ratio as 0.45, 20mm, and 1:4, respectively. A pavement slab suitable for low traffic volume roads designed as per IRC SP62: 2004 [4]. Feasibility of porous pavement at Hatkeshwar area of Ahmadabad city examined rainfall and traffic volume study data. The comparison was made between three major porous pavement types: porous concrete, porous asphalt, and interlocking pavers based on various properties [5]. A review paper suggested recapitulating the wide-range but scattered literature on primarily permeable pavement systems (PPS). The recent research and industry trends were advised, and future research and development areas were highlighted [6].

The curing time required by previous concrete was reduced by integrating a superabsorbent polymer (SAP). Harden cylinders were used for carrying out compressive Strength, unit weight, permeability, and void test. Enhanced workability and stronger void contents were obtained from results containing the SAP [7]. Experimental work was carried out on prominent factors such as the Strength and permeability of pervious concrete. This work intends to develop an innovative type of porous concrete with enhanced structural strength. A range of mix designs is carried out, and their effects on the compressive strength and permeability of pervious concrete are observed [8]. An overall study of cement paste properties indicating the result depending on water-cement ratio, type of admixture, and mixing time is examined. A minimum water-cement ratio of about 0.20-0.25 and 1% of superplasticizer helped inculcate a maximum allowable void ratio. An equation of previous brittle material, which can indicate the strength of pervious concrete was, suggested [9]. The suitable mix of cement, silica fume, superplasticizer, steel fiber, coarse aggregate, and so on for a pervious concrete pavement for road surfacing is determined. Trial mixtures with void contents ranging from 18.8 to 31.9% and densities from 1,890 to 2,034 kg/m3 gave satisfactory compression and flexural test [10].

The influence of fine and coarse aggregate quantities on the properties of pervious concrete is studied. Coarse aggregate ranging from 4.75mm to 19.5mm with fine aggregates of grading II and OPC type I are used. The relationship is developed between the Strength, abrasion resistance, permeability, and total void present in aggregate based on angularity number [11]. Pervious concrete for rural road pavement was studied as a case study. Cost comparison of normal concrete of M20 grade and pervious concrete was carried out. It was found that there was a considerable saving in amount about 29 Rs / m^3 or 193 Rs / m^2 or 18 Rs / $feet^2$ for construction of 1m x1m x 0.15m size pavement [12]. The study on no-fine concrete as road pavement was carried out by examining various properties and materials used in conventional and porous concrete. A substantial difference in the compressive strength was examined. A major thing found in no-fines concrete deformed more than the conventional sample before failure. [13]. Miniature examination on previous pavements was studied using an infiltration test. The conclusion suggests that pervious concrete is capable of infiltrating water at a decent rate. The infiltration rate of 312.64 inches/ hour indicates the benefits of implementing the pavement properly adhering to the rules [14]. Some researchers have also attempted to investigate previous concrete performance with marble sludge powder [15]. However, some researchers have also done an approach towards sustainable pavement [16, 17].

III. OBJECTIVE

This work aims to find the viability of pervious concrete as a pavement in Karanjade, Panvel. Following are the objectives:

1. To understand the traffic pattern of Karanjade Node by carrying out traffic volume study.
2. To study rainfall data of Karanjade area.
3. To design pervious concrete pavement using suitable IS code.

IV. METHODOLOGY

The methodology adopted for the research study is described in the form of a flowchart in Figure. 1. The chronological activities involved in this study are present in a graphical format. Details of pavement design are present in the subsequent headings.

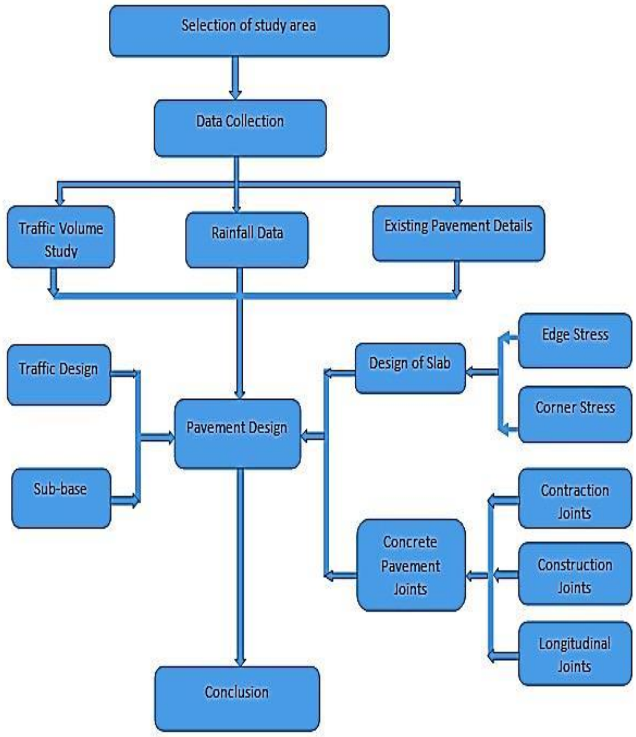


Fig 1: Flow chart of the methodology followed

A. *Study Area*

Karanjade is a panchayat village located in the Panvel Tehsil of Raigad district of Maharashtra, India. It is one of the developing villages at a faster pace. The approximate population of Karanjade is 3642. Its latitude is 18.9733° N, and its latitude is 73.1099° E. Karanjade area consists of marshy land with groundwater at a lesser depth. This area is facing drainage problems due to waterlogging and also has a low water supply. To study the above objective, rainfall data is collected. A traffic volume study is conducted in the internal streets of Karanjade area. Figure 2 shows a map of the selected area in Karanjade for research purposes, along with arm details.

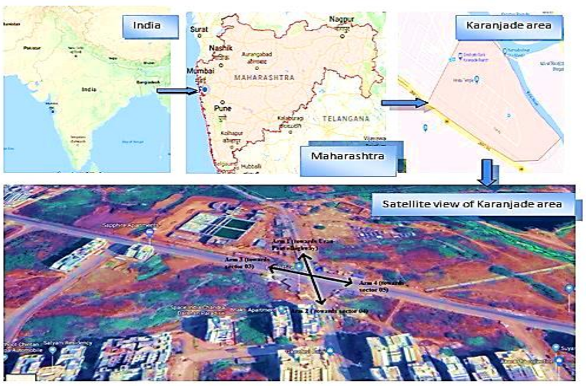


Fig 2: Karanjade map (Source: Google maps)

B. Traffic Volume Study

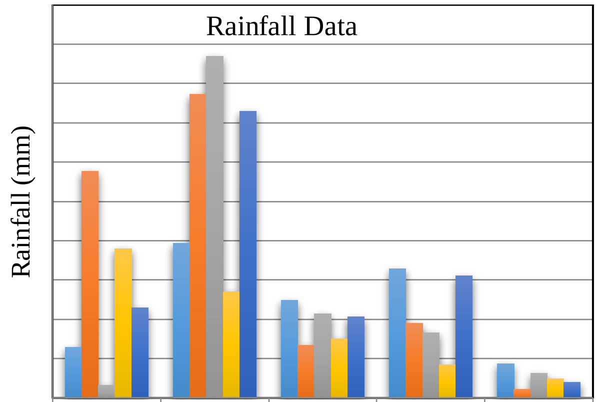
The traffic volume survey is carried out to check whether the existing roads are of low volume. It is done by the Manual Count Method. Mainly peak hours are studied. The study was carried out for 15 minutes time interval. Different types of vehicles are noted down with tally marking. A total number of vehicles passing and Passenger Car Unit (PCU) per hour are calculated. The study consists of four arms. Table 1 shows the vehicular data's details in the form of PCU/Hr. for the working day.

Table I
Traffic Volume Details for Working Day

Arms Name		Directions	No. of vehicles	Total PCU/Hr
Arm 1	Arm 1A	Karanjade Node to Uran Panvel Highway	892	483.75
	Arm 1B	Uran Panvel Highway to Karanjade Node	515	288
Arm 2	Arm2 A	Sector 04 to Karanjade Node	489	281
	Arm2B	Karanjade Node to Sector 04	250	150.75
Arm 3	Arm 3A	Karanjade Node to Sector 03	721	509.75
	Arm 3B	Sector 03 to Karanjade Node	433	339.5
Arm 4	Arm 4A	Sector 05 to Karanjade Node	909	606.5
	Arm 4B	Karanjade Node to Sector 05	492	366
Total average of PCU/Hr.				378.156

C. Rainfall Data

Rainfall data helped to find the total amount of precipitation that occurred during the last years. This data is important for the hydrological designing of pervious concrete pavement. Rainfall data of five years, i.e., from 2012 to 2016, was collected from Regional Agricultural Research Station, Karjat. Weekly rainfall data was analyzed. Mainly monsoon weeks were studied. Figure 3 shows its graphical representation of monthly rainfall.



	June	July	August	September	October
2012	258	787.4	496.6	656.4	174.6
2013	1154	1545.2	268	379.2	43.6
2014	63.8	1738.4	427	332.2	126
2015	760	541.4	300.4	168	97
2016	458.8	1457.8	411.8	620.8	79.5

Fig 3: Graphical representation of rainfall

(Source: Regional Agricultural Research Station, Karjat)

D. Existing pavement details

Traffic volume study helped to understand the traffic occurring in each arm. From Table 1, we can conclude that arm 2B has less volume of traffic. Therefore Arm 2, i.e., road joining Karanjade node to sector 4, is considered for applying pervious concrete pavement. The design details of existing pavements were studied and analyzed through the City and Industrial Corporation (CIDCO) plan. The details of the existing pavement can be

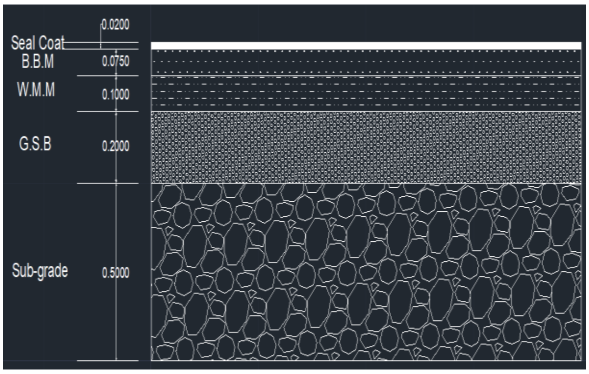


Fig 4: Cross-section of existing pavement

Seen from Figure 4, which gives the layer-by-layer specification. The existing pavement consists of a 20mm seal coat, 80mm B.B.M layer, GSB of 200mm thick.

E. Pavement Design

Indian Road Congress issued the first revision of IRC SP: 62 in 2014, which is used to design and construct concrete pavements for low volume roads [18]. Slab thickness of the pavement is a design by using IRC SP: 62 2014 [19]. For the compressive test and flexure test, mix design was prepared for M20, M30, and M35. However, the results articulated that the compressive Strength obtained from the M35 grade concrete is suitable for designing pavement. The flexural strength required for design is considered from the beam flexural test, which is 3.95MPa, and the compressive test value is 28.20MPa. The total traffic is 56 commercial vehicles per day for arm 2. Table 2 shows various design inputs considered for the design of pavement.

TABLE II Design Inputs

Design Inputs	Values (Units)
Present traffic	56 c.v.p.d
Wheel Load	$50x10^3$
Tyre Pressure	0.8MPa
Design Period	20 years
Modulus of sub-grade reaction (k)	50 MPa/m or $50x10^{-3}$ MPa/mm
Modulus of Elasticity concrete (E)	30,000 MPa
Poisson's ratio (μ)	0.15
Flexural Strength	$3.95N/mm^2$

a) Design Traffic

In the following section, Eq. 1 represents the total number of cumulative commercial vehicles at the end

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

(Clause 3.4, IRC-SP 62-2014, pp3) ….Eq. (1)

= 675868 commercial vehicles

The design period, where r signifies the rate of traffic increase, which is considered as 0.05, n, represents the design period, which is considered 20 years. The value of A is considered from Eq. (2), representing initial CVPD after completing the road, where P signifies initial CVPD.

$$A = P(1+r)^x = 58.8 \approx 59 \text{ CVPD}$$ ….. Eq. (2)

The current CVPD is less than 150 CVPD, so fatigue cannot be an actual problem; hence, fatigue fracture calculation for the pavement thickness is unnecessary. (Note x = construction period and is taken as 1 year)

b) Characteristics of Sub-grade

The Strength of subgrade is articulated in terms of modulus of subgrade reaction, k. Stresses in concrete pavement are not very sensitive to minor variation in k values. Hence, its value for a homogenous soil subgrade may be obtained from its soaked CBR value. Assuming 8% CBR value, by interpolation k value is calculated as 48.67MPa

c) Sub-base

Water Bound Macadam Grade III (WBMIII) or Wet Mix Macadam should be 75mm as per calculation over a granular layer of 100 mm Specification for WBM III as per IRC: 19-2005 size and compacted thickness of the layer should be from 53mm to 22.4 mm, and sieve sizes should be 63 mm, 53mm, 45mm, 22.4mm, 11.2mm, which should pass aggregate percentage by weight as 100, 90-100, 25-60, 0-15, 0-5 respectively. Commercially available IRC accredited stabilizers with no harmful leachate also may be used if found successful in trials.

e) Concrete Strength

Concrete pavements mainly fail due to bending stresses; hence, it is essential to design them based on concrete flexural Strength.

$$f_f = 0.7 \text{ x } \sqrt{fck} = 3.71 \text{ MPa}$$

(Clause 3.7, IRC-SP 622014, pp. 6)…..Eq.(3)

Flexural Strength (MPa) is represented by Eq. (3), where f_{ck} signifies a characteristic compressive cube strength of 28.20MPa. For design purposes, 90 days of flexural Strength is required.

For considering 90 days
= 28 days flexural strength x 1.10

$= 3.95 \text{ x } 1.10 = 4.34 \text{ N/mm}^2$

f) Design of Slab

Determination of stresses is the major component in the design of the slab.

1) Edge stresses

Edge stresses are represented by Eq. (4), where h is assumed slab thickness, i.e., 200mm, and the value of a and l is taken from Eq. (5) and (6).

$$\sigma_e = \frac{0.803P}{h^2} \text{ x } \left[4 \log \left(\frac{l}{a}\right) + 0.666 \left(\frac{a}{l}\right) - 0.034 \right]$$

(Clause 4.2.1, IRC-SP 62-2014, pp10) …….Eq. (4)

The radius of relative stiffness (mm) is represented by Eq. (5). E is the modulus of concrete elasticity, μ is Poisson's ratio for concrete, and k is the modulus of subgrade reaction in the foundation.

$$l = \sqrt[4]{\frac{Eh^3}{12(1-\mu^2)xk}} = 805.21 \text{ mm}$$ ….Eq. (5)

$$a = \left(\frac{P}{\pi \text{ x } p}\right)^{0.5} = 141.08 \text{ mm}$$ …..Eq. (6)

The radius of equivalent circular area for single wheel road is represented by Eq. (6), where P represents tyre pressure

$$a = \sqrt{\frac{0.8521\,Pd}{\pi x p} + \frac{Sd}{\pi}\sqrt{\left(\frac{Pd}{0.5227p}\right)}}$$

= 224.67mm ……..*Eq. (7)*

The radius of equivalent circular contact area for the dual wheel at the edge is represented by Eq. (7), where Pd signifies load on one wheel of dual wheel-set. The

$$\sigma_e = \frac{0.803x\,50x10^3}{200^2} x\left[4\log\left(\frac{805.21}{224.67}\right) + 0.666\left(\frac{224.67}{805.21}\right) - 0.034\right]$$

=2.378 MPa.

The value of 'a' in Eq. (7) is considered for slab thickness design. Substituting the values of Eq. (5) and Eq. (7) in Eq. (4), we get the value of edge stresses as shown below.

2) Temperature stresses at the edge

Temperature stresses are caused in pavements due to variation in temperature of the slab. During the daytime, the top portion of the slab is hot, which causes it to curl upwards, i.e., top convex, while at night, the bottom portion is hot, which causes it to curl downwards, i.e., top concave, as shown in Figure 6. The effect of temperature variation is at a very lesser amount at the corner but high at the edges

$$\sigma_{te} = \frac{E \propto t}{2} \text{ x C}$$

(Clause 4.2.1.2, IRC-SP 62 2014, pp. 11) …..Eq. (8)

Temperature stresses at the edge are represented by Eq. (8), where t shows the temperature difference (°C) between the top and bottom of the slab (20.3ºC). (CRRI) Central Board research institute recommends its values in the different zones in India. C is Bradbury's coefficient that depends on (L/l) as explained in Eq. (9) where L signifies joint spacing (270 mm)

$C = (\frac{L}{l})$ =2750/1081.90 = 2.51 ....Eq. (9)

By interpolation, C = 0.28

Substituting the value of Eq. (9) in Eq. (8), we get temperature stresses as shown below.

$$\sigma_{te} = \frac{30000x10x\,10^{-6}\,x\,19}{2} \text{ x } 0.28 = 0.798\text{MPa}$$

Total Stress = $\sigma e + \sigma_{te}$ = 3.176 MPa

< Flexural Strength (90 days)
i.e. 4.345MPa

As the total stress is less than the flexural Strength, so the assumed slab thickness of 200mm is safe.

3) Stress at corner

Corner stresses are represented by Eq. (10). At the corner wheel, load stress is less than flexural Strength, so the assumed slab thickness of 200mm is safe.

$$\delta e = \frac{\sqrt{2+1.2\mu}\,P}{\sqrt{E\,x\,h^3}}\left[1 - (0.76 + 0.4\mu)x\frac{a}{l}\right]$$

(Clause 4.2.2.1, IRC-SP 62 2014, pp 10)…..Eq. (10)

δe = 0.116 MPa< Flexural Strength (90 days)
i.e. 4.34MPa

4) Concrete Pavement Joints

Joints are provided in concrete to avoid cracks in it. Various types of cracks are provided for different places like contraction joints, construction joints, longitudinal joints.

a) Contraction Joints

Contraction joint spacing is between 2.5 to 4. It should be 3-5mm thick and 1/4 to 1/3 in depth. Dowel bars must be provided for the construction joint. They are provided for a slab thickness of 200mm or more than that. Table 3 shows specifications for dowel bars

TABLE III
Specifications for dowel bar

Slab thickness	Diameter (mm)	Length (mm)	Spacing(mm)
200	38	500	300

b) Construction Joint

Transverse construction joint can be provided when concreting is finished after a day's work or is suspended for more than 90 minutes.

c) Longitudinal Joint

Longitudinal joints are provided in the mid-width of the slab where the concrete slab's width exceeds 4.5m. Tie bars should be provided in the longitudinal joints. Table 4 shows the specification of tie bars.

TABLE IV Specification of tie bars

Slab thickness (mm)	Dia. (mm)	Maximum Spacing		Minimum Length	
		Plain Bars (mm)	Deformed Bars (mm)	Plain Bars (mm)	Deformed Bars (mm)
200	12	370	600	580	640
	16	660	1060	720	800

The rigid pavement design is based on the fact, for a load of any magnitude; its intensity reduces, as the load is passed on downwards from the surface by virtue of dispersal over an increasingly larger area, by carrying it deep enough into the ground through consecutive layers of granular material. The pavement thickness depends on the way in which loads are dispersed to the subgrade. Hence, the pervious concrete thickness layer was 200mm as per calculation, and it is found safe for edge and corner stresses. The succeeding layers are the bedding layer, base course, and sub-base course, having a thickness of 40mm, 100mm, and 155mm, respectively, which is diagrammatically represented in Figure 5.

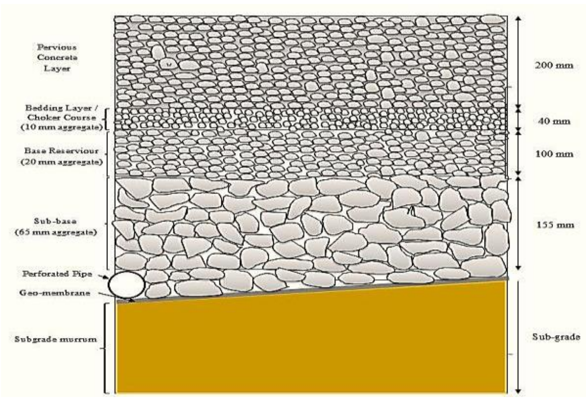


Fig5: Cross-section of designed pavement

V. CONCLUSION AND FUTURE SCOPE

- The rainfall data implies that the Karanjade area has average rainfall above 1000mm; hence, pervious pavement can be installed.
- Total average PCU/Hr. The study area's internal road is 379 PCU/Hr., which shows that the area has low traffic volume, which is observed to be suitable for pervious concrete pavement.
- The previous pavement design adopted with 200mm thickness was found to be safe.

An investigation needs to be carried out before the practical implementation of pervious concrete as pavement. Further work on hydrological behavior, pollutant removal, design life aspects, and approach towards improving the strength parameter of pervious concrete also need to be emphasized.

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