Theoretical Investigation on Pervious Concrete Pavement (PCP) as Sustainable Pavement Technology (SPT)

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Abstract. A pavement has always been in trend with lots of amelioration and furtherance. From gravel and cobblestone pavements to asphalt and concrete pavements, the world has seen a lot of new design criteria with the theoretical, field, and laboratory test analysis. From ages, the concept of Pavement has been holding on to improvising its esteemed characteristics such as compressive strength, durability, and life span. With varying mix designs and new methodologies of pavement evaluation and improvisation, the concept of sustainable pavements has gained enough priority. Better and durable quality with economical benefit and ecological balance is a much-needed pavement as per the present scenario of Mother-Earth. For a tidier society, the need for a new advancement in pavements has become crucial. With the rising revolution, Pervious Concrete Pavement (PCP) has paved its way straight to the top with an exceptional working mechanism in the category of Sustainable Pavement Technology (SPT). PCP has gained its empowered usage with beneficiary factors such as controlling storm-water runoff, reduction in pavement noise, providing vehicle-friendly pavements with a good riding platform, and being budget-friendly. With various conceptual studies and from several literature reviews, it is proven that PCP has become the future of pavement engineering with more add-ons and advantages. Therefore, this review paper, in particular, deals with the advancements of pavements, the necessity of sustainable pavements and, the transmogrification of Pervious Concrete Pavement. Following the theoretical concepts, the reviewed articles and proven test results will be scrutinized. This study concludes that available design mixes will be concentrated and accentuated for further analysis thus, proving PCP to be more efficacious in SPT.

1. Introduction
Transportation has been a major area of business economy for every country. The major import and export business deals with the mode of transport. Therefore, a country’s growth rate is closely influenced by the advanced transportation facilities that a country holds. Among the various transportation sectors, roadways are designated to be the most economical and easy of all. In this regard, the major concern is emphasized on the working ability of roads and as a part of it, various studies and experimental works are carried out upon the road and pavement quarter. The pavement plays a key role in giving cut-rate and comfortable transport. Adding to this context, the Indian government scrutinized the need for a pavement to be sustainable. Many pieces of researches have
been put forth and several proposals were made in the field of pavements. There has been a revolution of add-ons to the pavements and also amendments were suggested in the mix designs. As known already, pavements are categorized into flexible and rigid pavements with each one shouldering several assets and stags. Of the two, flexible pavements have proven to be more in use especially in the areas of major highways. According to research, seventy-eight percent of rural and eighty-six percent of urban highways in the United States are of flexible surfacing. It is experimentally suggested that the type of pavement is concerned with ground conditions and traffic flow. However, the carbon footprint analysis and budget assessment revealed that rigid pavements are a step more advanced than flexible pavement with lesser emission of energy and cut-rate[1]. In addition to the various considerations, there are several new reforms in sustainable pavement designs like pavements of hot mix asphalt, coarse grade asphalt, stone mastic, composite, etc., Unanimously pervious concrete has substantiated to be the most eco friendly with a lot more precedence. Pervious concrete pavement can be quoted as one of the emerging trends in sustainable pavement technology. Due to an increase in terms of energy emissions of conventional concrete along with a soaring rate of construction, there has been a desideratum for innovation. In addition to the levy and outpouring nature of concrete, excess precipitation crises have made a hike in the problem statement criterion. To resolve the nodus, the commencement of pervious concrete was made. Unlike the conventional concrete, pervious concrete authorizes the swirl of water into the ground and thus, gives the advantage of further utilization of the collected water. This paper entitles a crystal clear idea on the design criteria of pervious concrete pavement with the inclusion of various theories proposed by numerous authors accounting for the replacement of conventional concrete with pervious concrete.

1.1. Chronicle history
As per various citations available and information congregated, it is discernible that the first usage of pervious concrete is in the form of a pavement surfacing done in Europe in the early 1800s. The substantial usage is due to the prior requirement to cut down the content of cement used in the construction or paving of roads[2]. Later in England and Scotland, in the 1920s, pervious concrete was utilized in constructing two-storey buildings. But it became sought after the second world war where the availability of cement has fallen to the ground. In late 2000, India saw the rise of pervious concrete as an empowering guard. Well in advance with its evolving aids, pervious concrete has set a mark in the pavement area as the most satisfying paving surface that holds tremendous pros.

1.2. Materials and mix proportioning of PC
Pervious concrete(PC) works on the principle of permeability. In other words, the mechanism of Pervious Concrete Pavement (PCP) entails the porosity and thereby, diverting the action of porosity into a fringed aid of collecting the water. The PC comprises aggregates coarser than 9.5 mm mixed with normal portland cement along with water to attain a concrete mix with desirable voids [3]. The batching of materials is highly dependent on the requirement in the working area. Apart from the basic mix of pervious concrete, a little amount of fine aggregate can also be added just in case of enhancing the strength properties [4]. But for its porous nature, the PCP has attained many merits and has been a constant work field in the Sustainable Pavement Technology(SPT)[5]. The mix design of pervious concrete is likely to vary but a standardized ratio of aggregate to cement is found to be 1:3 for concrete of M20 grade [6]. However, it is notified that the strength of the PC can be escalated with the addition of plasticizers and superplasticizers which reduces the water content and thereby, increases the strength properties. The minimum percentage of voids required for an easy permeability of water is stated to be 20% which would accommodate the strength desired along with an acceptable rate of infiltration. The predominant factor affecting the properties of PCP is the water-cement(w/cm) ratio. The value of w/cm would be so beneficial if it ranges from 0.26 to 0.4 [7].
1.3. Design considerations and construction of PCP
The design of pervious concrete pavement predominantly intensifies the mechanical properties like strength and stiffness characteristics. Also, PCP design thickness is expected to rely on hydraulic properties such as the rate of infiltration and the void percentage in the mix[8]. Depending upon hydrological cycle, the environmental aspects, and the rate of traffic flow, the PCP needs to be fashioned in the above-cited properties and needs to be paved with a thickness of 200 mm to 300mm to sustain the heavy loads and enormous traffic flow(in relation with the passenger car unit theory). Also, care should be taken while compacting the soil of the subgrade. It is known that if a soil is more compacted less will be the voids and as a consequence, permeability decreases resulting in stagnation of water on the pavement. The next major consideration in PCP usage is the rate of infiltration. For a PCP to be paved over soil, the minimal infiltration rate expected is 2.5 mm per hour. This context has cleared many norms that PCP can be used for any type of soil provided the minimal infiltration rate meets the design infiltration rate and in case of infiltration rate lesser than 2.5 mm per hour, pivot tubes are inserted in the subgrade to regulate and divert water to constrained channels [9]. It is foremost to have a proper subgrade to avoid failures. Well experienced and efficient workmanship is a must to have a PCP laid. In rare cases where freezing and thawing are neglected, PCP can be directly placed over the subgrade with no requirement of subbase [10]. This needs to be determined only after a complete analysis of the site conditions and field tests of soil by the project manager. Furthermore, the slackening of water content creates a raveling effect on the PCP. To avoid the occurrence of raveling, the PC mix should be placed swiftly and curing needs to be done instantly to maintain the water content in the mix. This helps in the reduction of raveling nature and adds an aesthetic metallic finish to the PCP. Appropriate curing needs to be done to ensure a good pavement design with a longer life[11].

1.4. Engineering properties of PC
The various engineering properties of pervious concrete are stated in Table 1.

| ENGINEERING PROPERTIES | PERVIOUS CONCRETE |
|-------------------------|-------------------|
| Stiffness               | Stiffer than conventional concrete pavements |
| Placing                 | 1 hr to 1.5 hr (can be altered with addition of admixtures) |
| Slump                   | 20mm |
| Density                 | 1600 to 2000 kg/m³ |
| Void Content            | 15% to 25% |
| Permeability            | 80% more than Traditional concrete |
| Compressive Strength    | 3.5 MPa to 20 MPa |
| Flexural Strength       | 1MPa to 3.8MPa |
| Shrinkage(First 10 days of placement) | 50% to 80% |
| Abrasion Resistance     | Raveling and Abrasion is common |
| Sulphate Resistance     | More prone to get affected due to open pores |
1.5. Maintenance of PCP

The predominant excellence of PCP is the low service requirement. The cost of maintenance of pervious concrete pavement is comparatively lower than the conventional concrete pavement. Sometimes, it is observed that good pervious concrete pavement often results in zero maintenance for long years. However, in the case of the pores getting clogged on the top surface, removal of the debris and the waste material is recommended to revive the lost infiltration rate. Prior to the design of PCP, several factors like the elevation of surrounding drainages, presence of rocks, soil, residues, etc., should be cross-checked to avoid obturation of porosity. Vacuuming is one of the best courses of action to maintain the premiums of the PCP. Furthermore, pressure washing, sweeping, rinsing as well as power blowing can also be done to restore the permeability of the PCP. To avail of the methods of cleaning the PCP, the duration of decrease of permeability should be known. However, there are no accurate and definite methods of precise information. Rather, indirect methods are preferred. One such method is the Standard Test Method (ASTM C1701) where the PCP is tested for its infiltration rate at randomly noted points on the surface soon after the pavement is laid and ready for use. After a week, the procedure is repeated and the infiltration rate is compared to analyze the rate of dwindling of permeability. Based on the results, maintenance is often planned and executed[13].

1.6. Advantages of PCP

There are numerous aids and merits of PCP as a sustainable pavement technology. Table 2 stipulates the traits of pervious concrete pavement.

Table 2: Merits of PCP[14]

| GRADE                  | ASSETS                                                                                         |
|------------------------|------------------------------------------------------------------------------------------------|
| Appearance             | 1) More attractive than asphalt pavements  
                           2) metallic finish  
                           3) Rice-Krispie texture |
| Cut-Rates              | 1) Best surrogate to management of stormwater.  
                           2) Low maintenance.  
                           3) Budget friendly with low construction cost.  
                           4) Economy on Rain Water Harvesting can be cut short.  
                           5) Life-cycle cost is low |
| Environment Aspect     | 1) Eco Friendly in nature with lesser emission of heat  
                           2) Hydrological cycle is more effectively utilized.  
                           3) No stagnation of precipitation over the road thereby, reducing runoff.  
                           4) Enhances the groundwater table.  
                           5) Rate of pollution is dwindled |
| Structural Aspect      | 1) Prevents hydroplaning  
                           2) Provides a smoother travel in cases of rain and snow  
                           3) Reduction in the glare during night |
2. Literature Reviews

Several pieces of research have been made and numerous reports were submitted in favor of replacing conventional concrete pavements with pervious concrete pavements. Adding further, the crucial anchor is categorizing pervious concrete pavement as one of the sustainable pavement technology. In this aspect, many theoretical, laboratory, and field tests were conducted and several proposals are depicted in favor of PCP. Few such literature reviews concerning the PCP are as follows.

John T. Kevern et. al. (2012) carried an experimental analysis on the working procedure of previous concrete pavement concerning the Urban Heat Island Effect (UHI). In his research, he clearly stated the advantage of replacing conventional pavements with pervious concrete pavement for better sustainable pavement technology. Sensors that detect temporal variations are taken as the key materials in the test procedure and they are installed in both conventional and pervious concrete pavement at varying depths. After a five-day analysis, the storage of heat for each day is calculated for both conventional and PC pavements. From the results, it is experimentally proven that PCP has stored less energy in comparison to conventional type pavement. Consecutively, the UHI effect can be dwindled in PCP due to low heat stored property. The predominant inducement leading to low heat storage is the presence of voids in the PCP, which acts as a heat cutter for the pavements[15].

Hilal El-Hassan et. al. (2018) stated that the weighty succor of a pervious concrete pavement is to reduce the rate of runoff. He instigated the inclusion of ground granulated blast furnace slag commonly known as GGBS to the PCP. With the additive incorporation of polypropylene fibers, it is observed that the PCP has exhibited high porosity with low compressive and tensile strength. Experimental analysis was done on a PCP with GGBS of 50%, aggregates of 10 mm, and 20 mm. The results inferred that the PCP has exhibited a better performance in the name of low UHI effect, low carbon emissions (reduced by 54% in comparison to conventional concrete pavement), and of course a less cost of construction and maintenance. It is quoted that a 40-year life can be achieved with the removal of dust and debris at regular intervals. Furthermore, he proposed an inverse relation of permeability with aggregate size and direct relation with porosity[16].

Youngmin Joung et. al. (2008) emphasized greater concern on the strength characteristics of pervious concrete pavement. Research work was directed in the urban stream to optimize the drawbacks concerning the strength characteristics. As known already, urban areas are more prone to stagnation of rainwater due to improper drainage facilities. To counteract this trend, PCP is regulated to have more permeability. But permeability being inversely proportional to strength parameters, an increase in infiltration rate decreases the strength of the pavement. To provide a balance, the void ratio to be maintained without disturbing both strength and permeability characteristics is found to equalize 33%. Future research to compensate both parameters is also on the verge of completion in this regard[17].

Dale P. Bentz (2008) has given a virtual approach in association with pervious concrete pavements. The outcome of his analytical research profounds the virtual representation of the voids in the PCP. A 3D visualization was set up using the data from past researches, records, and chronicle data. He evaluated the three-dimensional structure of the pervious concrete pavement by considering a small section of it. A correlation between the permeability characteristics following percolation and transport of percolated water is formed. Initially, the 2D hybrid HCSS working model was used in developing the images of the void structure of PCP in 2D. Later, after obtaining all the data relevant to the development of 3D models, the venture of percolating void structure has come into the picture. In addition to the data represented, the author has involved the virtual grant of PCP in other aspects like clogging, freezing, and thawing resistance as well [18].

Malhotra. V. M (1976) stated the various properties dealt with pervious concrete pavement as a sustainable concrete pavement. It was experimentally found that the engineering properties of PC are more likely to differ from the conventional type of concrete. The density of pervious concrete was found to be 70% of the traditional concrete with the same constituents. He also instigated that
the use of rammers or vibrators in compacting the PCP would result in more compaction thereby lowering the voids and as a result, decreasing the permeable nature of PCP. He also added that properties like skid resistance are comparatively more for PCP than conventional concrete pavements. This has provided a clear way of making PCP more worthy of increased positive outcomes [19].

John Tristan Kevern (2008) quoted the need to look into the effect of freezing and thawing in the case of PCP. The amount of cement paste is much less in PCP as compared to conventional type pavement making it vulnerable to the freeze-thaw effect. There are tremendous chances of the coarse aggregate getting exposed to the open atmosphere due to the lack of intense coating of cement paste around them. In this aspect, the durability criteria were mentioned as one of the supreme contexts. There are direct test procedures in measuring the workability of conventional concrete but there is no such comfort for pervious concrete to date. Indirect means were focused to know the standards of pervious concrete. The ease to lay PCP and the density is considered in explaining the workability of pervious concrete as a pavement material. Also, the less water content ratio of pervious concrete strengthens the process of non-uniform curing thereby, resulting in the raveling of the pavement surface. A long term investigation and future scope on the strengthening of PCP was being carried out by them with a preliminary focus on pavement aging and distress problems to be minimized [20].

Rohini Lomte (2018) illustrated the advancement of PCP in accordance with mechanical and hydraulic properties. She stated the dependency of strength on the constituents of PCP. From the study conducted, it is scrutinized that no coarse aggregate of size less than 10mm is to be used and also amplified the need to avoid the flaky and elongated type of aggregates. From the research done, the nominal air content for an optimistic PCP is given as 13% to 28%, aggregate to cement ratio as 4:1. In furtherance to the study, admixtures like crushed granite, VMA, HRWR, superplasticizers were also recommended [21].

Suraj F. Valvi et. al (2017) demonstrated the study of pervious concrete pavement concerning factors affecting the sustainability of pavement. From the test analysis, it is evidenced that the mechanism of PCP needs to alter to suit the ground and climatic conditions especially in rural areas that come under the zone of heavy rainfall. Stormwater runoff is the most hectic factor that needs a large scale focus and with the replacement of conventional concrete with PCP, the majority of the snag is sorted. With a well planned and sophisticated construction of PCP, the hitch of overflow is controlled and also a phase of water table recuperation is observed. The results from the experiment stated that with an increase in the duration of the PCP construction, the permeability rate also increases with durability and strength remaining unchanged. Also, an inverse relation is quoted between water absorption and durability of concrete. Apart from all the known data, a keynote was added explaining the strength variation with change in grade of cement. According to this research paper, OPC 53 grade cement with an aggregate of 9.5 mm in a mix of 1:6 sounds to have higher compressive strength than any other mix. But the standard mix proportion preferred in PCP is 1:3 mix [22].

Darshan S. Shah et. al (2013) elucidated a coherent explanation of the cost-effectiveness of PCP in rural areas where land sustainability is at high risk. This research paper depicted the need for replacing traditional pavements with PCP to reduce the runoff of stormwater, escape the high budget construction and maintenance of pavements, enhance the level of the water table, effective use of land, and reduction in pollution. Following the design considerations, a PCP should be constructed based on the traffic flow and effective road utilization. It is preferably used in areas of low traffic and just in case of heavy flow, additives are suggested to enhance the strength of pavement [23].

Mary Vancura et. al (2011) posed a straight clear-cut exegesis of the structural dependency of PCP. Quotidianly, PCP is designed for serving the purpose of transportation as well as a stormwater management system. PCP plays a dual role when it comes to the working procedure. Thus, it is mandatory to heighten the strength parameter as well as the infiltration rate. As compared to
conventional concrete pavement, PCP lags in the value of elasticity modulus, compressive, tensile, and flexural strengths and also in subgrade modulus. This paper has provided a solution to maintain the desirable patterns without lowering the permeability of the PCP. After an evidential study and fieldwork, with proper thickness of the pavement and base course, an acceptable bearing capacity can be achieved. Reverse calculation of deflections to load, thereby comparing the deflection from falling weight deflectometer and simulations of ISLAB2005 using the Westergaard model has given a conclusion that the bearing capacity of both conventional and pervious concrete pavement can be equalized. Furthermore, the increase in modulus of rupture along with thickness is directly proportional to the fatigue life of PCP. Apart from the structural point of view, external factors like maintenance and removal of clogged materials also add up to the successful working of PCP with low cost of maintenance as a sustainable pavement technology [24].

3. Conclusion
From the performed theoretical study, it is perspicuous that the pervious concrete pavements have been emerging in the trend of sustainable pavement technology with new alterations in the aspect of design and materials. After a long appraisal of various considerations, PCP has ratified several advantages over conventional pavements in terms of better infiltration rate, reasonably economical in both construction and maintenance, environmentally sound with non-polluting and energy-efficient aspects. In addition to the excellence of PCP, it has been authenticated to be a quintessential alternative to counteract the Urban Island Effect. With the increasing demand for land sustainability, the pervious concrete pavement has given a good source of replacement thereby utilizing the infiltration rate for recuperating the dwindling groundwater table and also been a source to take the edge off for stormwater management. Further researches are being made in the flow to find solutions to some mechanical problems like stiffness and strength. But a reduced pavement thickness and less content of cement usage have made pervious concrete pavement to stand as one of the best replacements for conventional pavements. In accordance with the traffic flow and bearing capacity, experiments are still in progress. From all the analysis performed various characteristics of PCP, it is absolutely and utterly clear that Pervious Concrete Pavement (PCP) can be termed as a Sustainable Pavement Technology (SPT).

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