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A Review of Structural Performance of Pervious Concrete as a Sustainable Pavement Solution

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Abstract - *Pervious concrete is a novel way to paving that is gaining popularity as a result of its environmental benefits. In addition to various other advantages, pervious concrete pavement allows storm water to permeate through the pavement, reducing or eliminating the need for additional control structures. As a result, it is seen as a greener alternative to typical asphalt and concrete pavement systems. The purpose of this study is to provide an overview of pervious concrete and its use as a pavement.*

1. INTRODUCTION

xPervious concrete has an open cell structure that enables water and air to move through it [1]. It is made out of gravel or stone, cement, water, and little or no sand. Pervious concrete is a type of pavement that is extensively utilised as an ecologically friendly alternative to regular asphalt and concrete pavement. Figure 1 shows a typical portion of pervious concrete paving with open cell structures that enable storm water to pass through the pavement and into the underlying soils. As a result, pervious concrete functions as a drainage system and aids in the protection of the pavement's surface and environment. When compared to typical asphalt and concrete pavements, it also offers significant structural, economic, and environmental advantages [2]. It creates a drier surface during a rain event, making these systems safer for drivers. It also produces less noise than traditional systems, and it could eliminate the need for other types of stormwater treatment, such as retention ponds, which can be both expensive and impractical in many situations.

The first time porous concrete was used was in 1852 in the United Kingdom, when two dwellings were built out of gravel and concrete. Porous concrete has continued to gain favour in Europe as cast-in-place load-bearing walls of multistory homes and prefabricated panels, owing to the low cost of the cement employed. Pervious concrete became popular in the United States in the 1970s because of its permeability properties [3].

Thousands of pervious concrete projects have been constructed in the United States, Europe, and Japan during the last thirty years. Parking lots, sidewalks, pathways, tennis courts, patios, slope stabilisation, swimming pool decks, green house floors, zoo areas, shoulders, drains, nose barriers, friction course for highway pavements, permeable based under a normal concrete pavement, and low volume roads are some of the common applications for pervious concrete [4]. Pervious concrete is also frequently utilised as a surface course for roadway applications in Europe and Japan, where porous concrete is a layer over the impermeable layer to increase skid resistance and minimise traffic noise. Because it retains rainfall and recharges the soil, it is suggested for environmental reasons [5].

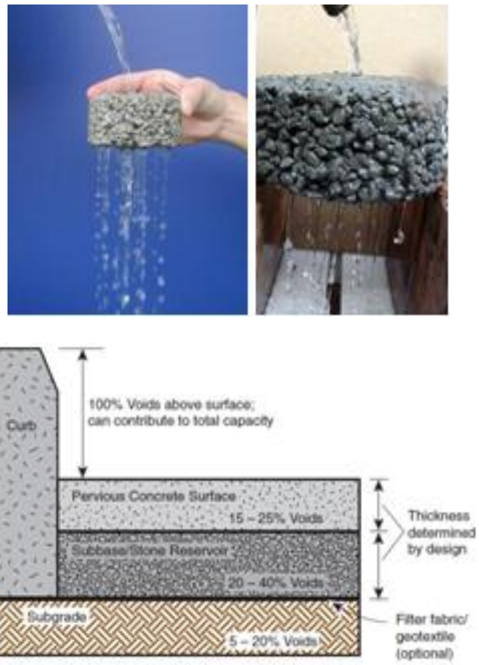

Figure 1. Pervious concrete permeability property and typical pavement cross-section [4]

1.1 MATERIALS AND MIX PROPORTIONS

Except for the proportions of materials, the fundamental constituents of pervious cement concrete mix are relatively similar to those of conventional cement concrete mix. Pervious concrete is made up of cementitious materials, water, coarse aggregate, and sometimes admixtures, just like conventional concrete, but it includes little or no fine aggregate. To generate a system of high porosity and linked voids, a suitable amount of cement paste is utilised to coat and bind the aggregate particles together. The empty content ranges from 15% to 25%, with the average being about 20%. [1].

Aggregates: Particles: For pervious concrete, the aggregate gradation is commonly made up of single-sized coarse aggregates or a binary combination of coarse aggregates. The aggregate size ranges from 19 to 9.5 mm [1]. The addition of tiny amounts of fine aggregates (less than 10% of total aggregate weight) can gradually reduce void content while increasing strength. Pervious concrete has been made with rounded and crushed particles, both standard and lightweight. Physical parameters of the aggregate, such as size and shape, have a substantial impact on the properties of pervious concrete [6, 7]. The size, shape, and gradation of aggregates have an impact on the compressive strength of pervious concrete. Uniformly graded aggregate has a higher compressive strength and void ratio, and is also better for field installations since it is more difficult to over-compact [8]. According to certain research, dolomitic aggregates give better compressive strength at higher porosity levels than equivalent limestone/slag aggregate combinations [9]. For many years, recycled aggregates from demolished buildings have been employed in many regions of the world [10]. This method is also environmentally beneficial.

Cementitious materials: Portland cements, mixed cements, slag cement, natural pozzolans, and fly ash are among the cementitious materials that can be employed. The total cementitious material content in the mixture is critical for compressive strength and void structure formation. Inadequate cementitious content might result in less aggregate paste coating and lower compressive strength. The ideal cementitious material content varies by aggregate size and gradation, but it usually falls between 260 and 415 kg/m^3.

Mix proportioning: The goal of pervious concrete mix proportioning is to achieve a balance of voids, strength, paste content, and workability. To determine optimal mix proportions using locally accessible components, experimental batches must be created [1]. When it comes to achieving the necessary porosity and strength, the water-to-cementitious material ratio (w/c) is crucial. A high w/c lowers the paste's adherence to the aggregate, allowing it to flow and fill the gaps, as seen in Fig. 2. A low w/c prevents proper mixing and uniform distribution of cement paste, lowering the concrete's final strength and durability. To provide adequate cement coating for the aggregates, the water-to-cement ratio is altered between 0.28– 0.40, which is lower than in traditional concrete mixes, where the water-to-cement ratio is typically between 0.38 and 0.52 [3]. According to certain research, a 0.45 w/c ratio is excellent for no-fines concrete [11].

Depending on the ultimate use, the aggregate-to-cement ratio might range from 4:1 to as high as 6:1. The aggregate-cement ratio utilised in construction applications typically varies from 6:1 to 10:1, with strengths ranging from 5 MPa to 15 MPa. Concrete strength is particularly important in pavement applications, and aggregate-cement mixtures as low as 4:1 are employed to guarantee enough bonding between the aggregate and cement to sustain the greater stresses. When compared to other aggregate/cement ratios of 8:1 and 10:1, a 6:1 aggregate/cement ratio had the maximum compressive strength, which might be advantageous for a pavement that required low compressive strength but good permeability. The smaller the coarse aggregate size, the higher the compressive strength and, at the same time, the higher the permeability rate [7].

Figure 2. Samples of pervious concrete with different water contents: (a) too little water, (b) proper amount of water, and (c) too much water [3]

Khattab et al [12] looked into the effect of mix proportions on the characteristics of porous concrete. A total of twelve different combinations were cast and tested. Sand was used to replace 10% of the coarse aggregate. Slump, density, and compaction index tests were performed on new concrete. Compressive strength, splitting tensile strength, flexure strength, permeability, and flow rate were all tested on hardened concrete. The inclusion of sand, as well as the usage of graded coarse aggregates and increased cement paste volume, all contributed positively to compressive, flexural, and cracking tensile strengths.

Admixtures: Chemical admixtures can be added to a mixture to gain or improve certain qualities. A viscosity altering admixture, an air entraining agent, and a high-range water reducer were utilised as additives. These admixtures were employed to enhance the binding between the cement and the coarse aggregate as well as the workability of the cement. Super plasticizers in pervious concrete can greatly improve its strength. The low water content in porous concrete pavement mixtures causes them to dry fast, thus retarders are also utilised.

Fly Ash: Fly ash can be used to replace up to 20% of the cement in pervious concrete. It improves the low slump mix's placement and finishing properties, as well as its workability.

2 ENGINEERING PROPERTIES OF PERVIOUS CONCRETE

Pervious concrete has a lower compressive strength, better permeability, and a lower unit weight than ordinary concrete (approximately 70 percent of conventional concrete).

Density: In comparison to traditional concrete, which has a void ratio of around 3-5 percent, pervious concrete has a void ratio of 15-40 percent, depending on the application. The large vacancy ratio results in a low unit weight of around 70% of that of standard concrete [7].

Porosity / Permeability: The porosity of a specimen is defined as the volume of voids divided by the total volume of the specimen. A water displacement method [13] can be used to determine the overall porosity of pervious concrete. Porosity should be between 15 and 25 percent [3]. The water-to-cement ratio and compaction effort are also factors that influence porosity [1]. Greater porosities (also known as void contents and void ratios) allow for higher infiltration rates but reduce compressive strength significantly. A falling-head instrument developed from soils testing is used to determine the permeability of porous concrete, while various methods have been used. According to the findings, permeability rose exponentially as the void ratio increased, and porous concrete with a porosity of less than 15% had limited or no permeability [13].

Compressive Strength: Pervious concrete's compressive strength can range from 3.45 MPa to 27.58 MPa, whereas standard concrete's compressive strength typically varies from 20.68 MPa to 48.26 MPa. Flexural strengths of pervious concrete and conventional concrete typically vary from 1 MPa to 3.8 MPa and 4 MPa to 5.5 MPa, respectively [3]. Although porosity is the primary determinant of compressive and flexural strength, aggregate size, shape, and gradation can significantly influence pervious concrete strength [8]. The compressive strength of porous concrete is directly proportional to the unit weight of the mix, and as the unit weight grows, so does the strength. According to certain research, with the right water-cement ratio and densification technique, strengths of up to 21 MPa may be achieved [14]. Using admixtures, however, pervious concrete strengths higher than conventional traditional concrete strengths may be achieved, reaching up to 55.16 MPa [15]. This is related to the reduction of air spaces, which may result in a large reduction in permeability. Because the major purpose of a porous pavement system is to obtain enough permeability for storm water control, compacting concrete until it reaches adequate strength is not always a possibility, and a balance between strength and void ratio must be established [14].

Durability: Pervious concrete has a problem with surface durability. Even with adequate batching, handling, and curing, ravelling can occur in pervious concrete. The surface durability of pervious concrete may be tested using existing ASTM test techniques [16, 17]. A laboratory test that evaluates the ravelling of pervious concrete has been developed for measuring the surface durability of pervious concrete [18]. Distress surveys were conducted on two distinct field locations as part of an examination into structural performance, and the data were utilised to create a pavement condition index (PCI). The thicker pervious concrete sections' high PCI ratings demonstrated that, when correctly planned, pervious concrete may be utilised for most "Residential" and many "Collector" roadways for average design life periods while demonstrating satisfactory structural performance [19].

3. DESIGN CONSIDERATIONS

When utilising pervious concrete, three design aspects must be taken into account:

i) mixture design/proportioning,

ii) hydraulic design, which is comparable to stormwater detention ponds and has programmes and guidelines available from various national sources [20], and

ii) structural design.

Structural pavement design: Any standard concrete pavement process (e.g., AASHTO) [21] can be used to design pervious concrete pavements. PerviousPave, a complete tool created by the American Concrete Pavement Association, may be used to produce both structural and hydrological designs for pervious pavements [22]. There are currently no thickness guidelines for pervious concrete pavements, however many parking lots have pervious pavements that are 150 mm thick, whereas low-volume roadways have pervious pavements that are between 150 and 300 mm thick [1]. The following are the considerations to consider while designing pervious concrete pavements.

Subgrade and subbase. A composite modulus of subgrade response, which accounts for the impacts of both the subgrade and the subbase, is commonly used to describe foundation support. Under previous concrete pavements, an open-graded subbase is typically utilised to offer a path for vertical water drainage as well as storage capacity.

Concrete flexural strength. Concrete's flexural strength is an essential factor in the structural design of concrete pavements. Compressive strengths are often measured, and empirical relationships are used to determine flexural strengths for use in design [3].

Traffic loading applications. The majority of pervious concrete pavements are utilised in low-traffic areas. The amount of traffic that a pervious pavement is expected to carry is generally expressed as comparable 80 kN single-axle load repetitions.

4. CONCLUDING REMARKS

The study discussed the relevance of pervious concrete and its advantages as a sustainable pavement system that has been widely utilised for over 30 years for roadway applications in Europe, the United States, and Japan. The article included a wide range of pervious concrete qualities, including mix proportions, mechanical properties, environmental considerations, and cost-benefit analysis.

When compared to other non-pervious pavements, permeable concrete pavement offers a significant benefit in reducing storm water runoff. Pervious concrete is a suitable material for use in pavements because of its high water flow rate and light weight. This feature has led to the increased usage of pervious concrete in metropolitan areas to improve storm water quality and reduce rainfall runoff. Pervious concrete's poor compressive strength, on the other hand, limits its use in areas with moderate traffic loads and volume. Because of its porosity, the material's strength is rather low. The strength and abrasion resistance of pervious concrete may be considerably improved by using appropriate aggregates, fine minerals, admixtures, organic intensifiers, and modifying the concrete mix percentage. It offers good qualities that may be used in road pavement applications despite its low compressive strength.

Pervious concrete mix appears to be a very attractive option for use as a pavement material in low-volume roadways such as local streets, pedestrian walkways, and driveways, and maybe in highways in the future if mechanistic-based design techniques are established, according to published studies. Based on prior study, it was discovered that there are various research gaps in the field. If these gaps are recognised and investigated, they can aid in the overall knowledge of the material and contribute to the formulation and implementation of pervious concrete pavement design guidelines.

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