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Research Paper

Pervious Concrete

Engineering

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ABSTRACT

Water logging is a major issue at parking and walkways, especially during rainy season, as pavements and floors are normally impermeable. This result in post construction activities like excessive repairs and providing unnecessary storm water drain systems, which are not only costly but may also get clogged during peak flow. Thus, it becomes very important to think of an economical solution which helps in getting rid of all above problems. The best solution to above problem is pervious concrete.
Pervious Concrete is a special concrete used to allow water to intentionally pass through the surface of a pavement and allow storm water to eventually absorb back into the surrounding soils or evaporate. This study evaluates the factors affecting the strength and hydraulic parameters of pervious concrete, presents results of long-term infiltration monitoring and cleaning operations. The specific objectives of this study are to determine compressive strength of pervious concrete cube after 28 days curing; determine the infiltration ratio of pervious concrete slab. Determination of flexural strength of pervious concrete slab is also done.

INTRODUCTION

As urbanization increases in India and many parts of the world the problem of water logging and requirement of drainage is also increase. This is partly due to impervious nature of the bituminous and concrete pavements. Pervious concrete which has an open cell helps significantly to provide high permeability due to its interconnected pores. Pervious Concrete is a special concrete used to allow water to intentionally pass through the surface of a pavement and allow storm water to eventually absorb back into the surrounding soils or evaporate. This keeps runoff water from downstream urban flooding and erosion. It also breaks the cycle of water treatment plants needing to treat storm water where municipalities have combined sewer and storm water systems.

Pervious concrete pavement has a 12 year history in Pennsylvania, a 25 plus-year history in Florida and other southeastern states, and over 50 years in Europe. In addition to storm water control, pervious concrete pavement is a sustainable building product that aids in reducing the urban heat island effect and will provide 30+ years of low maintenance service at a low life-cycle cost. (1) There are four advantages of pervious pavement:

- Water treatment by pollutant removal.
- Less need for curbing and storm sewers.
- Provides a means to recharge local aquifers.
- Less mass grading is required to create drainage gradients; pervious concrete is ideal for flat areas. (1,2)

India is facing a typical problem of ground water table falling at a fast rate due to reduced recharge of rainwater into subsoil and unplanned water withdrawal for agriculture and industry by pumping. NFC if adopted for construction of pavements, platform/walkways, parking lots designed for lighter load. Pervious concrete can be successfully used in India in applications such as parking lots, driveways, gullies/sidewalks, road platforms, etc. Over the next 20 years there is expected to be a significant amount of housing construction India. The roads around the apartments/ homes and the surfacing inside the compound can be made with pervious concrete.

Massive urban migration in Indian cities is causing the ground water to go much deeper and is causing water shortages. For example, in states like Tamil Nadu residents commonly pay for water delivered and it is not uncommon to receive water only for a few days of a week in many parts of the country. Flooding and extended water logging in urban areas is common since all the barren land which could hold the rain water are being systematically converted into valuable real estate with a result that impervious surfaces such as roads, parking lots, roof tops are covering the natural vegetation. It is indeed ironical that even the world's wettest place Cherrapunji suffers drought while the monsoons brings flooding. Further, the rain water that falls on the concrete and asphalt surfaces tend to carry a high level of pollution and this pollution ends up in our waterways ultimately. The use of pervious concrete can help alleviate the damage of all of these ills. (1,2)

Another significant advantage in India as compared to Western countries is the significantly lower cost of labor. Much of the pervious concrete construction is manual and can be done without heavy equipment and therefore pervious concrete can be placed at a lower cost even in rural areas. A caution though is the higher prevalence of airborne dust in India that could lead to clogging of the pervious concrete. Pervious concrete can function with no maintenance and some level of clogging. Nevertheless, frequent preventative maintenance is recommended.

In apartment communities, resident associations could perhaps take this over and those applications could be the first ones to be attempted. In future with increased urbanization, diminishing ground water levels and focus on sustainability, technologies such as pervious concrete are likely to become even more popular in India as well as other countries. (2,3)

Pervious Concrete has been around for hundreds of years. The Europeans recognized the insulating properties in structural pervious concrete for their buildings. Europeans have also used pervious concrete for paving including on the Autobahn. Pervious concrete was brought to the United States after World War II. It first showed up in Florida and other southern coastal states. Slowly it has migrated to the other states where it has met different successes. As with any new product, it has had to prove itself. Many well intended ready mix producers have produced the product and many well intended contractors have placed the product. (1)

Due to the new regulations by U.S. Govt. on storm water runoff, it has become more expensive for property owners to develop real estate, due to the size and expense of the necessary drainage systems. Pervious concrete paving reduces the runoff from paved areas, which reduces the need for separate storm water retention ponds and allows the use of smaller capacity storm sewers. This allows property owners to develop a larger area of available property at a lower cost. Pervious concrete also naturally filters storm water and can reduce pollutant loads entering into streams, ponds and rivers. Pervious concrete functions like a storm water retention basin and allows the storm water to infiltrate the soil over a large area, thus facilitating recharge of precious groundwater supplies locally. All of these benefits lead to more effective land use. Pervious concrete can also reduce the impact of development on trees. A pervious concrete pavement allows the transfer of both water and air to root systems allowing trees to flourish even in highly developed areas (3)

LITERATURE REVIEW

In 1852, Richard Langley used a predecessor of pervious concrete for the construction of two concrete houses on the Isle of Wight in the United Kingdom. This concrete consisted of only coarse gravel and cement. It is not mentioned in the published literature again until 1923, when a group of 50 two-story houses were built with clinker aggregate in Edinburgh, Scotland. In the late 1930s, the Scottish Special Housing Association Limited adopted the use of pervious concrete for residential construction. By 1942, pervious concrete had been used to build over 900 houses.

After Eight years of research by Ferguson, B. K., (University of Georgia) he concluded with the first comprehensive review of porous pavement technology and applications resulting in the book, *Porous Pavement*, authored by Bruce Ferguson. It defines nine families of porous paving material each of which has distinctive costs, maintenance requirements, advantages and disadvantages for different applications, installation methods, sources of standard specifications, and performance levels.(3, 4)

Later Cement and Concrete Technology Center, (Cemex) on his paper characterizes different mixture designs using a proposed test that measures the filtering capabilities in relation to compressive and flexural strengths. The tests analyze the individual and accumulated influence of different factors that take part in the filterable concrete design, such as cement content, the addition of different percentages of sand, or the use of additives that modify the fresh-state properties

Wanielista, M. and Chopra, M. (University of Central Florida) describes the pervious concrete system and its corresponding strength are as important as its permeability characteristics. The strength of the system not only relies on the compressive strength of the pervious concrete but also on the strength of the soil beneath it for support. Previous studies indicate that pervious concrete has lower compressive strength capabilities than conventional concrete and will only support light traffic loadings. This project conducted experimental studies on the compressive strength on pervious concrete as it related to water cement ratio, aggregate-cement ratio, aggregate size, and compaction. (2,4)

Manoj Chopra, (University of Central Florida) in his presentation focuses on the hydraulic operations of a pervious concrete system including infiltration rates, storage capacity and clogging potential. A method of testing for the in situ infiltration rate of a pervious concrete system–an embedded single ring infiltrometer has been developed and will be presented. The study consists of detailed analyses of several pervious concrete parking lots that have been in operation for 5 or more years.

According to RMC Research Foundation Funding Pervious concrete pavements are growing in popularity but study of their long-term performance is still needed in order to evaluate and improve them. An updated evaluation of the long-term field performance of pervious concrete pavement will be helpful not only to the concrete industry but also to design and permitting communities and end users. The study will evaluate current pervious concrete pavements of various ages with differing soils, environmental conditions, and geographical locations. The final report will include recommendations for changes in designs, construction, and maintenance of pervious concrete pavements. (1,3)

According to Journal of Materials in Civil Engineering, Volume 7, Number 4, November 1995b, pages 286 to 289 Ghafoori, N. and Dutta, S. No fines concrete is defined as a type of concrete from which the fine aggregate component of the matrix is entirely omitted. The aggregate is of a single size and finished product is a cellular concrete of comparatively low strength and specific weight. The cellular nature eliminates capillary attraction and provides greater thermal insulation and water permeability than exists in conventional concrete. The advantages of no–fines concrete for different construction purposes have long been recognized.(5)

Concrete International, American Concrete Institute, August 1988, pages 20 to 27. Meininger, R. C. Results of a laboratory study of no-fines pervious concrete for paving are presented. Conclusions are drawn regarding the percentage of air voids needed for adequate permeability, the optimum water-cement ratio range, and the amounts of compaction and curing required. Recommendations are made regarding appropriate uses for this type of concrete. (6)

According to Portland Cement Association Pervious concrete is made from carefully controlled amounts of water and cementitious materials used to create a paste that forms a thick coating around aggregate particles. Unlike conventional concrete, the mixture contains little or no sand, creating a substantial void content between 15% to 25%.(5)

Current applications are not as focused on building construction as they were in the past but today, pervious concrete is primarily used for the paving of parking lots, driveways or sidewalks.

Materials and Methodology

Pervious concrete, also known as porous, gap-graded, permeable, or enhanced porosity concrete mainly consists of normal Portland cement, coarse aggregate, and water. In normal concrete the fine aggregates typically fills in the voids between the coarse aggregates.

In pervious concrete fine aggregate is non-existent or present in very small amounts (<10% by weight of the total aggregate). Also, there is insufficient paste to fill the remaining voids, so pervious concrete has porosity anywhere from 15 to 35% but most frequently about 20%. (1,5)

Aggregate grading used in pervious concrete are typically either single-sized coarse aggregate or grading 3/4 and 3/8 in (between 19 and 9.5 mm). A wide aggregate grading is to be avoided as that will reduce the void content of the pervious concrete.

All types of cementations materials such as fly ash, slag cement; natural pozzolanas conforming to their ASTM specifications are used. Pervious concrete can be made without chemical admixtures but it is not uncommon to find several types of chemical admixtures added to influence the performance favorably. Since pervious concrete has a low workability, it is important to maintain it to provide sufficient working time at the jobsite. Therefore, retarding admixtures or hydration stabilizing admixtures are useful. Viscosity enhancing agents are also beneficial as they can help add more water without causing paste drain down and hence can improve workability. (3,5)

basic mix design

Cement & Cementations Materials

1. Portland Cement Type I, II or I/II is readily available in the market and used for pervious concrete production.(ASTM C150)

2. Slag Cement (Ground Granulated Blast-Furnace Slag, aka. GGBFS) is a cementations material available in the market and used in pervious concrete production. (ASTM C989)

3. Fly Ash is available in the market and used in pervious concrete production. (ASTM C618) (3)

Slag and fly ash are supplementary cementitious materials often used to replace the amount of cement. They both offer good benefits to concrete and they offer strength gain which means they add durability in the long run. Both require longer curing times for the concrete to initially set and gain strength.(7,8)

Aggregates

- Aggregates can have a direct influence in the permeability, surface texture and the appearance of the pervious slab.

- A uniform large aggregate size is preferable for maximum permeability. This is opposite of the optimized gradation usually wanted in a regular concrete mix.

- The size of the large aggregate will have an effect on aesthetics and the top size of the “holes” in the surface.

- ¼” to ½” large aggregates are preferred.

- The specific gravity shall be >2.5 and the absorption shall be <2.5 to aid in durability and performance.

- Both rounded aggregates like pea gravel and angular aggregates like granite, quartzite and limestone have been used in the market. Experience tells us that the rounded aggregates can pack tight in the placement process, limiting some of the permeability. The angular aggregates have some limited drawbacks too, such as making it a little harder to get out of the trucks and increasing water demand slightly. Both have benefits and limitations.

- For the most part, sand is excluded. However, research has shown up to 6% fines in the mix can provide added durability without losing porosity.

- The hardness and durability of the aggregate can also have an effect on the durability of the pervious pavement.

- The aggregates should be good quality clean aggregates. Dust and debris can add to clogging the wet pervious matrix. (1,5)

Water

- Water used for the pervious concrete mix shall be potable, drinkable water.

Admixtures

- Air entraining admixtures can be used. Dosages usually start at 2 oz/cwt

- Water reducing admixtures can also be used. Dosages for pervious concrete can exceed the ranges typically used for conventional concrete. A starting dosage rate of 6 oz/cwt is recommended.

- Hydration stabilizers also known as extended control admixtures.

- Viscosity modifying admixtures (VMA’s).

- New admixtures for pervious are appearing every day. Recently admixture companies have bundled together water reducers, hydration stabilizers and viscosity modifying admixtures in one product to market for pervious mixes. These have been met with mixed reviews. (5)

Mixture proportioning

Void Content

At a void content lower than 15%, there is no significant percolation through the concrete due to insufficient interconnectivity between the voids to allow for rapid percolation. So, concrete mixtures are typically designed for 20% void content in order to attain sufficient strength and infiltration rate. (4)

Water- Cement Ratio

The water-cementitious material ratio (*w/cm*) is an important consideration for obtaining desired strength and void structure in pervious concrete. A high *w/cm* reduces the adhesion of the paste to the aggregate and causes the paste to flow and fill the voids even when lightly compacted. A low *w/cm* will prevent good mixing and tend to cause balling in the mixer, prevent an even distribution of cement paste, and therefore reduce the ultimate strength and durability of the concrete. *W/cm* in the range of 0.26 to 0.40 provides the best aggregate coating and paste stability. The conventional *w/cm*-versus-compressive strength relationship for normal concrete does not apply to pervious concrete. Careful control of aggregate moisture and *w/cm* is important to produce consistent pervious concrete.(9-11)

Cement Content

The total cementitious material content of a pervious concrete mixture is important for the development of compressive strength and void structure. An insufficient cementitious content can result in reduced paste coating of the aggregate and reduced compressive strength. The optimum cementitious material content is strongly dependent on aggregate size and gradation but is typically between 267 and 415 kg/m3.

The above guidelines can be used to develop trial batches. ASTM C1688 test can be conducted in the laboratory to observe if the target void contents are attained. (1,2)

TESTing OF pervious concrete

Testing Pervious Concrete

- There are 2 ASTM tests designated specifically for pervious concrete.

- ASTM C1688, Standard Test Method for Density and Void Content of Freshly Mixed Pervious Concrete

- ASTM C1701, Standard Test Method for Infiltration Rate of In Place Pervious Concrete.

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- Compressive strength of concrete to be determined after 28 days curing.

- Flexural strength of pervious concrete slab.

ASTM C1688 (Density & Void Content)
- This test method provides a procedure for determining the density and void content of freshly mixed pervious concrete.

- This test method is applicable to pervious concrete mixtures containing coarse aggregate with a nominal maximum size of 25 mm [1 in.] or smaller.

- This test method covers determining the density of freshly mixed pervious concrete under standardized conditions and gives formulas for calculating the void content of pervious concrete.

As such there is no Code available for Pervious Concrete. As per ASTM C 1688, Slump & air Content test are not applicable to pervious Concrete. Fresh density has been measured & comes to 2120 Kg/ Cum. (Average weight of Cube is 7.15 kg) (3)

ASTM C1701 (Infiltration Test)
- This test method covers the determination of the field water infiltration rate of in place pervious concrete.

- Tests performed at the same location across a span of years may be used to detect a reduction of infiltration rate of the pervious concrete, thereby identifying the need for remediation.

- As per ACI 522 R -06, Drainage rate of Conc. Pavement will vary from 2 to 18 gallons / min/sqft. In our case it comes to 4.5 to 6.0 gallons/min./sqft(4)

Infitration test of pervious concrete cube

Figure 1: infiltration test

Source: www.googleimages .com

Alternate method of testing of Pervious concrete slab for Infiltration rate (ASTM C1701).

Figure 2: alternate infiltration test

Sources: www.googleimages .com

Pervious concrete slab of dimension 45cmx45cmx4.5cm

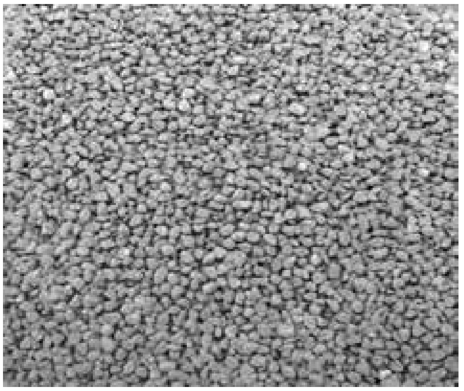

Figure 3: pervious concrete slab sample

COMPRESSIVE STRENGTH OF PERVIOUS CONCRETE
Total trials includes tests of no fines were conducted at our concrete laboratory. Cubes were cured in curing tanks so as to create exact site conditions.

FLEXURAL STRENGTH OF PERVIOUS SLAB
Mix shall be proportioned with durable materials to achieve a 28-day compressive strength of 3000 psi and a 7 day and 28 day flexural strength of 300 and 500 psi respectively. Flexural testing of pervious concrete slab in universal testing machine conducted in **Corporate Institute of Research and Technology,** Bhopal.

Figure 4(a): flexural testing machine

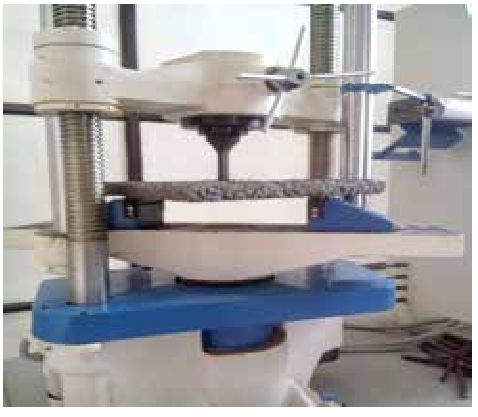

Figure 4(a): flexural testing of sample

RESULT

COMPRESSIVE STRENGTH TEST (WITH NO FINE)

TABLE – 1
COMPRESSIVE STRENGTH

Age (Days)	Wt. of Cubes (Kg)	Strength (MPa)
28	5.260Kg	30MPa

FLEXURAL STRENGTH TEST

Length of slab = 45cm , width of slab =4.5cm

TABLE – 2
FLEXURAL STRENGTH

Material Used	Flexural strength	Wt.of slab
Pervious Concrete	3.05KN/mt3	13.380kg

Result obtained after flexural test =6.1x5=30.5xleast count(0.1)=3.05kN/mt3

WATER ABSORPTION TEST

TABLE – 3
WATER ABSOPTION

Material Used	Wt .of slab before dipping into water for 24 hrs	Wt. of slab after 24 hrs
Pervious Concrete	5.260 kg	5.680 kg

So total water absorbed in % = 5.680-5.260=0.420 kg=0.08%

Application of pervious concrete

Common applications for pervious concrete are parking lots, sidewalks, pathways, tennis courts, patios, slope stabilization, swimming pool decks, green house floors, zoo areas, shoulders, drains, noise barriers, friction course for highway pavements, permeable based under a normal concrete pavement, and low volume roads. Pervious concrete is generally not used solely for concrete pavements for high traffic and heavy wheel loads. (11-15)

ENVIRONMENTAL BBENIFITS

Pervious concrete allows storm water to infiltrate into the ground to replenish ground water aquifers. It retains storm water so that retention ponds are not needed for parking lots. Keeps pavement surfaces dry even in wet situations, such as greenhouses. This allows parking lots to be ice-free in freeze/thaw areas since snow melt immediately drains off the surface. This also allows water and air to get to the roots of trees within a parking area. Aerobic bacteria that develop within the pavement and base can break down oil and remove other pollutants from the water that washes off the surface. Light reflectivity is higher than with asphalt surfaces, reducing any heat island effect. It can collect irrigation and retain water to be used for irrigation. (16-18)

ECONOMIC BENEFITS

A parking lot properly constructed from pervious concrete has a life span ten times as long as an asphalt lot, thereby providing excellent long term benefits. It is true that the initial costs for pervious pavement may be slightly higher due to the preparation of the sub-base, but those who look long term will realize the economic benefits. (6) As far as the material goes, pervious concrete is installed in a thicker quantity than conventional concrete, usually six-inches (15 cm.) vs. four-inches (10 cm.). However, one must look beyond the costs per square foot, at the product that overall system. (18-21)Pervious concrete is a sustainable saves money in the long run for the following reasons:

- Lower installation costs due to the elimination of costly curbs, gutters, storm drain outlets and retention basins that cost two to three times more to construct than pervious.
- Less money will be needed for labor, construction and maintenance of ponds, pumps, drainage pipes and other storm water management systems.
- Allows for the use of existing storm sewer systems for new developments.
- Increase land utilization since there is no need to purchase additional land for large retention ponds and other filtering systems.
- Lower life-cycle costs equal to that of conventional concrete that if properly constructed will last for 20 to 40 years.
- Pervious requires fewer repairs than asphalt, and can be recycled once it has reached its lifecycle.
- Recent reports from multiple regions around the U.S. indicate that the cost for asphalt binder has recently increased as much as 50% and more, resulting in dramatic cost increases for asphalt pavement.
- Easy maintenance that consists primarily of prevention of clogging through pressure washing and power vacuuming. (1,3,6)

COST COMPARISON

TABLE – 4
COST COMPARISON

Type of Pavement	Rate* (Rs./Sqft)	Perviousness	Remarks
Kota Stone	100	Impervious	Drainage Required
Shahbadi Stone	110	Impervious	Drainage Required
Kaddapa Stone	120	Impervious	Drainage Required
Ferro Concrete Block	125	Impervious	Drainage Required
Normal Concrete	80	Impervious	Drainage Required
Pervious Concrete	75	Pervious	Drainage not Required

Source: www.perviouspavement.org,www.pervious.info/

CONCLUSION

Pervious concrete is a cost-effective and environmentally friendly solution to support sustainable construction. (3) Its ability to capture storm water and recharge ground water while reducing storm water runoff enables pervious concrete to play a significant role. (1,6) Pervious concrete is a smart sustainable option with very high potential. Pervious concrete is an ideal solution to control storm water, re-charging of ground water, flood control at downstream and sustainable land management. Due to its low cost construction, if it gets utilized in Indian context then it proves to be very beneficial to solve environmental issues and water logging problems which are the major issues in India. (3) Pervious concrete is the brightest star in the green building movements, according to past research history. It really a jump starts for our hurting industry right now, if we can do research to improve its basic properties then it has much bright start for its application in India. This study focuses on long term infiltration performances of pervious concrete parking lots and their storm water management credit. (3,4) Concrete's clean look creates a good first impression and lasting sense of quality. Concrete can be fashioned with an array of decorative textures, shapes, patterns and color(1,2,3).

FUTURE WORK

Applications have been focused on parking lots and pedestrian pavements. More field applications of pervious overlays, low volume streets, highway shoulders, medians and swales need to be researched for additional concrete opportunities. With the wide variety of placement techniques (plate compactor, vibratory screed, roller, high density paver), an attempt to standardize the equipment used is important. Compaction effort affects many properties of pervious concrete that are used for Quality Assurance/Quality Control (QA/QC) purposes **(3).** As pervious pavement applications widen, attention will eventually turn to quicker turn around on opening pervious pavements. No research has been focused in that area. Clogging, whether surface or within, needs to be further researched in terms of being able to monitor volume loss over time and the maintenance techniques that can be used to recapture volume. Removing cores for clogging observation is not a perfect since water is used to remove cores which could disturb some of the sediment loading. Additional design elements due to heavy sediment loading which prevent failure of pavement are Hydrological and Environmental Design elements**.** Adsorption of grease and oil into pervious concrete pores and its long term impact, growth and decomposition of biomass and aerobic digestion in a pervious system, leaching of concrete materials into the groundwater and soils, byproduct research – cement kiln dust, high carbon ash, etc. should also be studied. Development of observation wells for water quality testing should be done.

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