An Experimental Investigation on Pore Structures of Pervious Concrete Using Digital Image Analysis

C. ROY[1], M. RANA[1], A. HOSSAIN[1], A. HASNAT[1], T. U. MOHAMMED[2]

[1]Department of Civil Engineering, University of Asia Pacific, Dhaka, Bangladesh (chiranjib.uap@gmail.com)
[2]Department of Civil and Environmental Engineering, Islamic University of Technology, Bangladesh (tarek@iut-dhaka.edu)

Abstract

Pervious concrete is one of the felicitous engineering tools to address the unexpected environment problems i.e. water logging, depletion of ground water table etc. However, the pore structure features (porosity, pore-sizes etc.) play a dominant role in the field of structural and functional performance of pervious concrete. But there has not any standard experimental procedure been developed yet to determine these properties precisely. With this background, this research work had been planned. The major objective of this study was to investigate the pore structures using "Digital Image Analysis". Accordingly, total 50 cylindrical specimens were prepared maintaining 0.35 water-cement ratio. Test items involved unit weight, void content, compressive and tensile strengths (28 days), water permeability etc. The experimental results revealed that the results obtained by image analysis appear to be more compatible than those of other traditional methods. Moreover, the higher proportions of larger size coarse aggregate provide pervious concrete with higher porosity and pore sizes.

Keywords: *Pervious Concrete, Digital image analysis, Pore Structures, Compressive and Tensile Strengths.*

1 Introduction

According to National Ready Mixed Concrete Association (NRMCA, 2010), pervious concrete is a special type of concrete with high porosity used for concrete flatwork application that allows water from precipitation and other sources to pass through it, thereby reduces storm water runoff and the concentration of pollutants and recharges ground water level as well. Typically pervious concrete consists of Portland cement, coarse aggregate, water and little or no fine aggregate. Using of uniform coarse aggregate promotes pervious concrete with higher porosity and permeability than conventional concrete, which enables quick drainage of storm water (Tennis et al., 2004). Pervious concrete is widely used across the world for its several advantages, such as reduction of downstream flows, erosion and sedimentation, large volume of surface pollution, decrease of urban heat island effect, eliminating traffic noise, enhancing safety of driving during raining etc.(Malhotra, 1976). In the past 40 years, pervious concrete had been increasingly used in USA and Europe, and was among the best management practices recommended by the "Environmental Protection Agency (EPA)" (Rana et al., 2013).

Since, the pore structure features, such as porosity, pore size ctc. are the key parameters of pervious concrete, it is indispensable to investigate these properties precisely to get better understanding about the structural and functional performance of pervious concrete. Even though, several researches had been conducted on pervious concrete in the past, these key features were not apparently determined due to the unavailability of sophisticated method. Moreover, these traditional methods are not substantial enough to investigate these properties more precisely. As a result, pervious concrete is not widely assigned in construction work in our country yet. Therefore, a novel sophisticated technique-"Digital Image Analysis" has been introduced in this study. The main objective of this study was to investigate the pore structure features of pervious concrete more precisely using "Digital Image Analysis". The whole image analysis procedure had been performed following the step-by-step process, which has been elaborately discussed in the methodology section of this paper. In this study, both physical and mechanical properties of pervious concrete have been determined. However, some difficulties and unusual results were also experienced by the authors while accumulating data from the image analysis. Eventually, this paper is an attempt to turn over a new leaf in the field of concrete technology in terms of permeable concrete, so that the practicing civil engineers and researchers would be convinced enough to assign this concrete as a suitable engineering tool for sustainable development in our country.

2 Methodology

2.1 Material Properties

In this research work, single type locally available first class brick aggregate was used as coarse aggregate. Fine aggregate was typically avoided in this study. The physical properties of coarse aggregate have been summarized in Table 1. The cement incorporated in this study was Portland composite cement (CEM II/B-M (S-V-L) 42.5 N). Potable tap water was used for the mixture purpose. Cement content (300 kg/m^3) and W/C (0.35) were identical for all the mixtures. The mix-design which was followed in this study has been summarized in Table 2 below. Five different cases had been prepared to determine the necessary outcomes. Aggregate combination "75 #4 & 25 #8" indicates that 75% CA retains on 4 no. sieve and the rest 25% is on 8 no. sieve. Digital image analysis software "Image J^{TM}" was engaged in this study to investigate the pore structures of pervious concrete.

Table 1. Summary of physical properties of coarse aggregate

Items	ASTM Specifications	Type of Aggregate (FB) (Avg. Values)
Specific Gravity (SSD)	C127	2.78
Specific Gravity (OD)	C127	2.46
Apparent Specific Gravity	C127	2.84
Absorption Capacity (%)	C127	9.57 (%)
Loss Angeles Abrasion (%)	C131(grade B)	30.65 (%)
Unit Weight	C 29	1563.21 (kg/m^3)

* *FB= First Class Brick.*

Table 2. Mix-Design of Pervious Concrete (for 10 specimens in each case)

Case Type	Aggregate Combination	W/C	A/C	C (Kg)	W (Kg)	CA (Kg)		
						# (3/8)″	#4	#8
Case A	100 #4	0.35	3.83	5.95	2.08	0.00	22.80	0.00
Case B	75 #(3/8)″ & 25 #4	0.35	4.11	5.95	2.08	18.34	6.11	0.00
Case C	75 #4 & 25 #8	0.35	4.19	5.95	2.08	0.00	18.70	6.23
Case D	50 #(3/8)″ & 50 #4	0.35	4.25	5.95	2.08	12.64	12.64	0.00
Case E	50 #(3/8)″ & 50 #8	0.35	4.41	5.95	2.08	13.12	0.00	13.12

* *W=Water, C=Cement, A=Aggregate, CA=Coarse aggregate.*

2.2 Mixing, Casting and Curing Details

A 200 litre pan type concrete mixer machine was used for the mixing purpose. The necessary amount of ingredients (cement, water, coarse aggregate) was estimated according to the mix design based on the total volume of concrete. Coarse aggregates were in SSD (Saturated Surface Dry) condition while mixing in the laboratory. Total fifty cylindrical specimens (100 mm x 200 mm) were prepared as per ASTM C192. Manual wooden hammer compaction was carried out to compact the freshly mixed concrete in the mould. The freshly consolidated concrete specimens (with mould) were kept under wet jute bags for one day. Then the specimens were removed from the mould and kept under wet jute bag for 28 days. The specimens were then kept under water for one day. The samples were then finally removed from water and carefully rinsed the surfaces with fresh water and kept in the open air for surface dry before the test.

2.3 Testing Procedure

2.3.1 Unit Weight of Pervious Concrete

The unit weight observed in this study was freshly mixed pervious concrete unit weight, which had been calculated following the ASTM specification (ASTM C 1688/C 1688M) just after the samples being casted. The following equation (1) was used to calculate the unit weight of pervious concrete in this study.

$$D = (M_c - M_m) / V_m \quad (1)$$

Where, 'D' is the Density or Unit weight of concrete (kg/m^3), 'M_c' is the mass of mold filled with concrete (kg), 'M_m' is the Mass of mold (kg) and 'V_m' is the volume of mold (m^3).

2.3.2 Compressive and Tensile Strengths Test

Both compressive and tensile strengths tests were carried out on the relevant specimens based on ASTM C 39 and ASTM C 496 respectively using the universal testing machine. Cylindrical specimens (100 mm x 200 mm) were prepared and tested after 28 days curing. The results have been reported as the average value.

2.3.3 Permeability Test

In this thesis work, a falling head permeability cell was designed to estimate the hydraulic conductivity of permeable concrete. The coefficient of permeability (k) was calculated using the following equation (2):

$$k = 2.303\ (aL/At) \times \ln(h_2 / h_1) \qquad (2)$$

Where, ‘a’ and ‘A’ are the areas of the cross-section of specimen and standpipe respectively, ‘L’ is the length of the specimen, ‘h_1’ and ‘h_2’ are the initial and final head respectively, and ‘t’ is the time (sec).

2.3.4 Measurement of Void (%) by Theoretical Method

In this study, the most crucial parameter “void (%) in concrete” had been measured following several strategies. Firstly, this parameter was determined theoretically using the following equation (3).

$$V_t = [1-\{D/(G_{sb}\times W_c)+ f_a\}]\times 100 \qquad (3)$$

Where, V_t is “Theoretical void (%) in concrete”; D is “Density or Unit weight (kg/m^3)”; G_{sb} is the “ Bulk specific Gravity (OD)”; W_c is “ Water content (kg)” and f_a is the “Air factor”.

2.3.5 Measurement of Void (%) by Volumetric Method

In this method, the selected specimens were immersed in a water jar marked with a scale. Then the increased volume of water was carefully measured. Thereafter the air bubbles were removed by gently shaking the specimen. Thus using those data the interconnected void was calculated following the equation (4) given below.

$$V_0 = (V_1 - V_2) / V_1 \times 100 \qquad (4)$$

Where, ‘V_0’ is the percentage of void in concrete, ‘V_1’ is the volume of cylindrical specimen with void and ‘V_2’ is the volume of increased water in container after immersion of specimen.

2.3.6 Measurement of Void (%) by “Digital Image Analysis”

The above mentioned traditional methods for the measurement of void (%) are not capable enough to determine this key parameter (porosity) of pervious concrete precisely. Therefore a sophisticated technique has been introduced in this study to investigate the porosity of pervious concrete by using “Digital Image Analysis”.

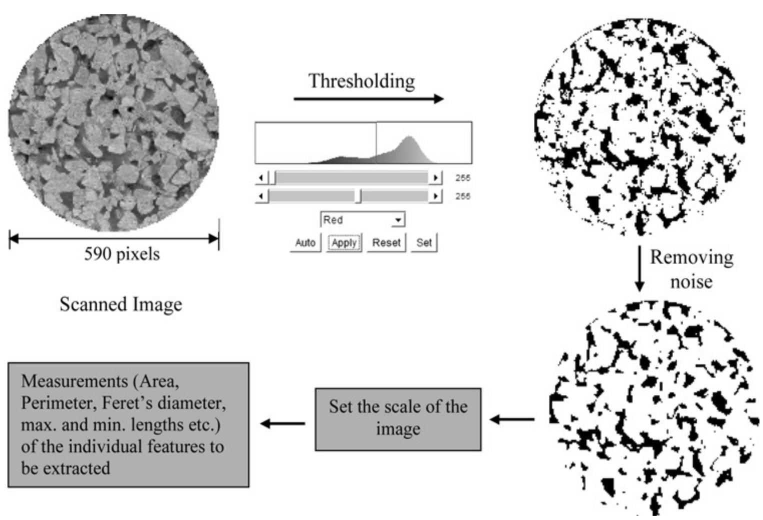

Figure 1. The steps of image processing and analyzing of “Image J Tm” software.

The Image J™ software (mainly used in medical science to investigate the fractures and the subtle pores in bone, available at (www.rsb.info.nih.gov) was engaged in this study for image analysis. This method follows several step by step processes from image processing to feature acquisition (Figure 1). Likewise, a 200 mm long specimen was sectioned along the length into 4 (50 mm each) thick slices. Then these slices were rinsed carefully with fresh water to remove the dust from the surfaces. Thereafter, the slices were kept in an oven to desiccate the water from surfaces and then carefully scanned (both sides) in the grayscale mode (JPEG format). Thus eight images from a single cylinder were accumulated for the overall image analysis process. In this thesis work an electronic scanner device was used for capturing the images of the specimens. The overall step by step processes of image analysis system have been outlined in Figure 2 below. Thus the pore structure features of pervious concrete have been investigated in this study with intensive care as well.

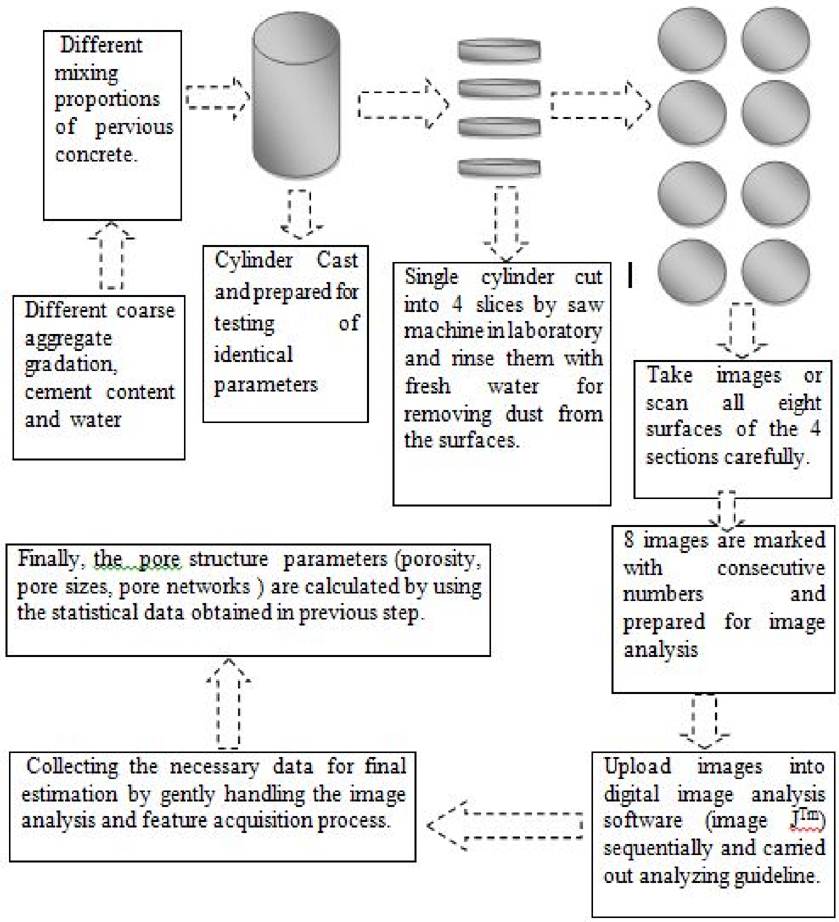

Figure 2. Step by step process in image processing and feature acquisition.

3 Results and Discussion

Unit weight of concrete of different mixture proportions has been shown in Figure 3(a). The results categorically reveal that the unit weight of pervious concrete varies with the gradation of coarse aggregate. It is also observed that pervious concrete made with 100 #4 coarse aggregate shows relatively higher unit weight than that of other cases. The measured values varied from 1538 kg/m^3 to 1588 kg/m^3 with an average value of 1555.46 kg/m^3. According to ACI 213R-87, pervious concrete having unit weight equal or below 1840 kg/m^3 is categorized as light weight concrete, which indicates that pervious concrete investigated in this study could be assigned as light weight concrete at the relevant construction site.

In addition, the variation of permeability against different aggregate gradations has been depicted in Figure 3(b). The values of permeability varied from 24 mm/sec to 56 mm/sec. The experimental results reveal that the pervious concrete made with larger size coarse aggregate (CA) contributes to higher permeability compare to that of smaller size coarse aggregate. This is because the smaller size aggregate fills up the inside void of the large size coarse aggregates and also interrupts the pore connectivity.

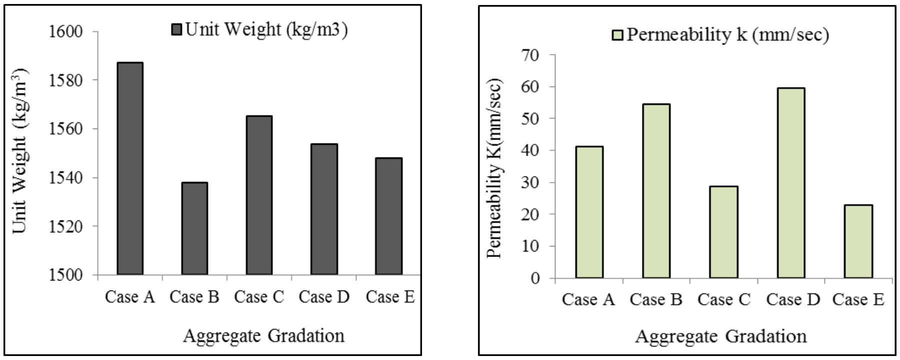

Figure 3. (a) Unit weight (left) and (b) Permeability of pervious concrete (right).

The variation of void (%) in pervious concrete obtained by several methods has been illustrated in Figure 4(a). Here it is observed that the permeable void (%) was found the highest compare to the rest two methods, which indicates that the cases of large size aggregate combination contain relatively higher interconnected pores. Void (%) achieved by image analysis varied from 20% to 32%, while the permeable void ranged from 26% to 38%. According to ACI 522-06, the typical void content of pervious concrete ranges from 15% to 35%, which indicates that the results obtained by image analysis are more satisfactory and also within the ACI standard ranges. Thereby, it could be invariably said that the development of "Image Analysis" is one of the best techniques to investigate the pore structure features of pervious concrete than other traditional methods.

Moreover, both compressive and tensile strengths of pervious concrete made with different types of aggregate gradation have been demonstrated in Figure 4(b). According to ACI 522-06, compressive strength of pervious concrete ranges from 2.76 N/mm^2 to 27.59 N/mm^2. In this study, compressive strengths of different cases varied from 6.19 N/mm^2 to 8.98 N/mm^2, which reveals that all values are within the ACI standard ranges. Similarly, tensile strengths were within the range of 0.85 N/mm^2 to 1.62 N/mm^2. It is also observed that the compressive strength is around ten times of tensile strength. However, case E (50 #3/8″ & 50 #8) shows higher values of both compressive and tensile strengths compare to the other batches, which suggests that the higher proportions of smaller size aggregate in the mixture provides pervious concrete with higher strengths.

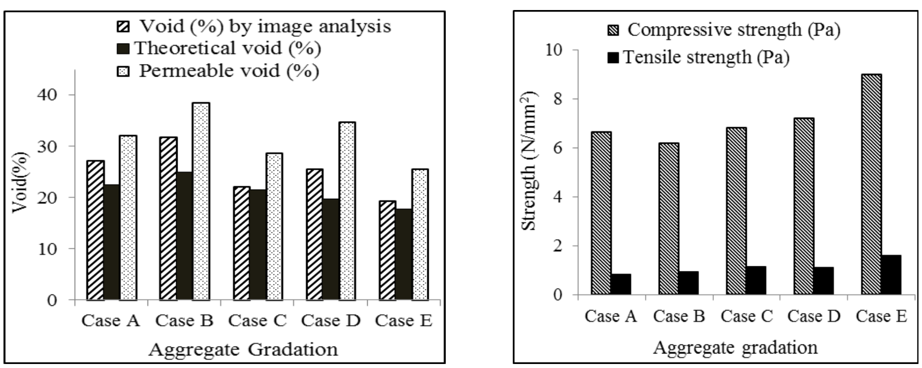

Figure 4. (a) Void (%) in pervious concrete (left) and (b) Compressive & Tensile strengths (Right).

The variation of void (%) with unit weight of pervious concrete of different mixture proportions has been shown by developing a relationship in Figure 5(a), where it is observed that void content in pervious concrete decreases with the increase of unit weight. The relationship between compressive strength and unit weight has been shown in Figure 5(b), where they are proportional to each other. Furthermore, the variation between compressive strength and permeability has been shown in Figure 5(c). These both parameters are inversely proportional to each other, which reveal that high permeable concrete is usually involved of less compressive strength. The most significant relationships of permeable void with permeability and void (%) by image analysis with permeability have been shown in Figure 6(a) and Figure 6(b) respectively. It is hereby observed that the both relationships have established the same trend apparently and are proportional to each other. The correlation between void (%) by image analysis and compressive strength has been shown in Figure 6(c), which reveals that the compressive strength increases with the reduction of void in concrete. However, some unusual results were also experienced while calculating the properties of pervious concrete. Eventually, more further researches are invariably necessary (specially 3D analysis for digital image analysis system) to get more precise out comes.

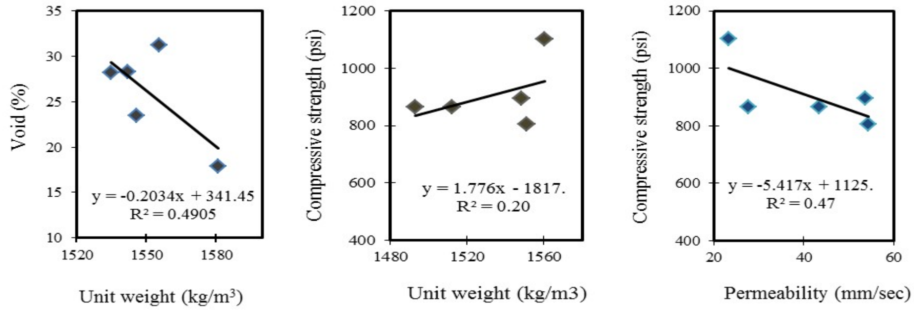

Figure 5. Relationship between (a) void (%) and unit weight, (b) compressive strength and unit weight and (c) compressive strength and permeability of pervious concrete.

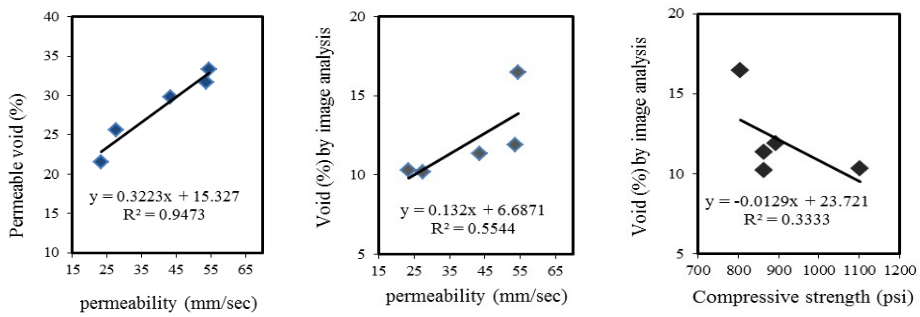

Figure 6. Relationship between (a) permeable void and permeability, (b) void by image analysis and permeability and (c) void by image analysis and compressive strength of pervious concrete.

4 Conclusions

The following conclusions could be summarized based on the scope of this study:

- Pervious concrete investigated in this study satisfied the ACI standard ranges with respect to the unit weight, compressive strength, void (%), and permeability.
- Pervious concrete made with larger sized coarse aggregate shows higher permeability and less unit weight compare to the conventional concrete.
- Digital image analysis has shown more compatible outcomes and satisfied the ACI standards as well.
- Digital image analysis could be considered as a felicitous technique to investigate the pore structure features of pervious concrete to some extent.
- Locally available first class brick aggregate can be used as a palatable engineering material to develop pervious concrete.

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