- Technical Paper -

EFFECT OF CLOGGING ON PERMEABILITY OF SINGLE AND DOUBLE LAYERED POROUS CONCRETE

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ABSTRACT

One of the most prominent issues facing porous concrete is that of clogging where the continuous voids get choked. This paper is an effort made to first study the clogging and its effect on the coefficient of permeability of POC, followed by an additional experiment to find a solution for clogging by creating a double layered POC and further to investigate the effectiveness of the upper layer made of smaller sized aggregates with smaller value of void ratio, in recovering the permeability by washing after the voids get clogged by the added silica sand.

Keywords: porous concrete, permeability, clogging, single layer, double layer.

1. INTRODUCTION

Porous concrete (POC) is a technology in which concrete has intentionally created continuous voids inside. These particular continuous voids are designed to allow the water and air to permeate through them, which in turn will enable POC to exhibit various environmentally friendly activities. To highlight a few of them, POC can be used to avoid creation of imbalance in natural ecosystem by the prevention of pollution of rivers, lakes and coastal waters, erosion, flash floods, water table depletion as rainwater rushing across pavement surfaces picks up everything from oil and grease spills to deicing salts and chemical fertilizers [1]. It can co-exist with micro-organisms; it can be used as a media for thermal and moisture-conditioning, plants and grasses can be grown on it to enhance the look as well as impart greening effect to areas like river protection works and barren slopes; it can also be utilized as noise barrier walls in railways and expressways.

The advantages of POC notwithstanding, there are a few problems facing POC. Potential areas of concern are: effect of cyclic wetting and drying, freezing and thawing, shrinkage cracks, repeated loading effect, abrasion, wearing and clogging phenomenon [2].

In this paper, two experimental studies have been carried out. The First experiment was on single layered POC samples the purpose of which is to study the clogging phenomenon and its effect on the coefficient of permeability (K_T) [3]. The second experiment was carried out on single and double layered POC with the aim to study if the coefficient of permeability could be restored by washing, after the occurrence of clogging phenomenon. The results and discussion in the following sections of the paper will throw light on the outcome of the experiments.

Table 1 Factors and testing levels (1st exp.: single layered POC) [3]

Factor	Testing Levels
Void ratio(%)	15, 23, 30
Size of Aggregate	G6*1, G7*2
Added sand (g)	0, 60, 120
[Vs/S.A*3 (cm^3/cm^2)]	[0, 0.4, 0.8]

Note: *1 Aggregate Grade G6 (5-13)mm, *2 Grade G7 (2.5-5)mm
*3 Vs: added sand volume, S.A: top surface area (150x40)mm

Table 2 Factors and testing levels (2nd exp.: double layered POC)

Factors	Testing levels
Size of Aggregate	G6*1, G7*2, G8*3
Combination of layers	(G6+G7), (G6+G8)
Added sand (g)	0, 60, 120
[Vs/S.A*4 (cm^3/cm^2)]	[0, 0.4, 0.8]
Thickness of top layer (mm)	4,8,12

Note:*1 G6 (5-13)mm, *2 G7 (2.5-5)mm, *3 G8 (1.25-2.5)mm
*4 Vs: added sand volume, S.A: top surface area (150x40)mm

Table 3 Experimental conditions (2nd exp.: double layered POC)

W/C ratio (%)	30%
Void ratio of upper layers (%)	18%
Void ratio of under layer (%)	23%
Under layer (50mm)	G6
Size of single/under layer	(50x150x40)mm

Table 4 Mix proportion

Sample	Unit weight (g/L)			
	water	cement	Aggregate	SP*1
G6*2	544.84	1816.13	8163.79	1.63
G7*3	167.33	557.55	1746.11	0.50
G8*4	161.5	538.57	1778.87	0.48

Note: *1 SP: Superplasticizer, *2 G6 (5-13)mm, *3 G7 (2.5-5)mm, *4 G8 (1.25-2.5)mm

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2. EXPERIMENTAL METHOD

2.1 First Experiment (Single layered POC)

Table 1 shows factors and levels of the first experiment. This experiment was carried out on single layered POC samples of size (50x150x40) mm. Samples with aggregate grades G6 of void ratios 15%, 23% and 30% along with G7 of void ratios 23% were used. Single block of POC was first cast and later cut into required sizes of the samples. Both the longitudinal faces of the samples have cut and ground surface to make them smooth and uniform throughout. This ensures that the samples fit in the apparatus perfectly so that water enters only from the top surface of the sample and comes out from the bottom surface. An indigenous apparatus as shown in Fig.4 was prepared to carry out the experiment. During the experiment, a water head of 50mm as can be seen in figure was maintained. In order to calculate the coefficient of permeability (K_T), water permeating through the sample was collected at the outlet for 10 seconds and weighed every time. Normal tap water was first allowed to pass through the samples. Then 60g each of grade G6 silica sand were added successively, once again taking the weight of the water collected for 10 seconds after each addition. The procedure was repeated for all the four samples. Clogging patterns were observed and its impact on behavioral change in K_T was calculated using the data obtained from the experiment.

2.2 Second Experiment (Double layered POC)

Table 2 displays the factors and levels and Table 3 shows the experimental conditions for the second experiment respectively. Table 4 shows the mix proportion for the three grade aggregate samples G6, G7 and G8. The procedure of the experiment is the same as in the first experiment. The only difference here is the introduction of double layered samples as opposed to the single layered ones in the first experiment. Here, single layered POC samples of grade G7 and G8 along with double layered samples of G6+G7 and G6+G8 were prepared for carrying out the clogging versus permeability tests. Fig.2 and Fig.3 represent the double and single layered samples. The under layer is of G6 aggregate with void ratio of 23% and the upper layers are of G7 and G8 aggregates with the void ratio of 18%. In this case, the double layered samples had three different thicknesses for the upper layer i.e. 4mm, 8mm and 12mm. The under layer is maintained of the same size as the sample in the first experiment i.e. 50x150x40mm. The void ratio of the upper layer has been intentionally kept lower than that of the under layer to try and stop as much added sand as possible on the surface itself and to simultaneously ensure the easy movement of the sand from the under layer after it enters from the upper layer. This flow mechanism by virtue of the difference in void ratios and aggregate sizes in the two layers is expected to facilitate the movement of sand entering in from the upper layer, till the bottom of the sample.

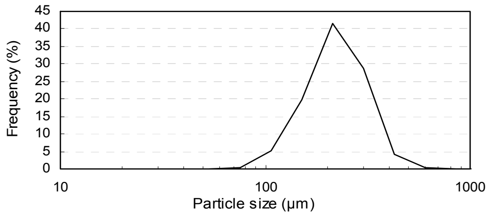


Fig.1 Particle size distribution of G6 silica sand

Fig.2 A double layered POC sample
Upper layer = 4,8 &12mm thick

Fig.3 Single/under layer sample (G6)

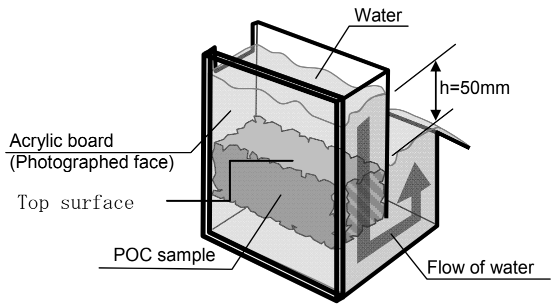


Fig.4 Apparatus used for the experiment [3]

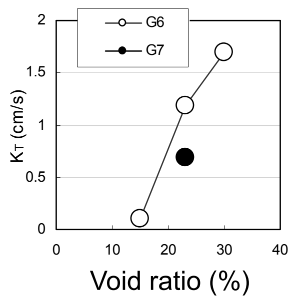
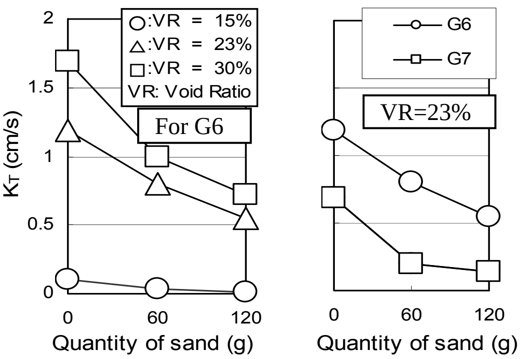


Fig.5 Relationship between K_T and void ratio [3]



(a) Void ratio (b) Agg. size

Fig.6 Effect of addition of sand on K_T [3]

3. RESULTS AND DISCUSSION

3.1 First Experiment (Single layered POC)

This experiment demonstrated that the permeability of POC is inversely proportional to the clogging phenomenon. As the added sand entered the voids of POC, clogging occurred and consequently reduced the coefficient of permeability of the sample. Fig.1 shows particle size distribution of silica sand.

(1) K_T of POC before the addition of sand

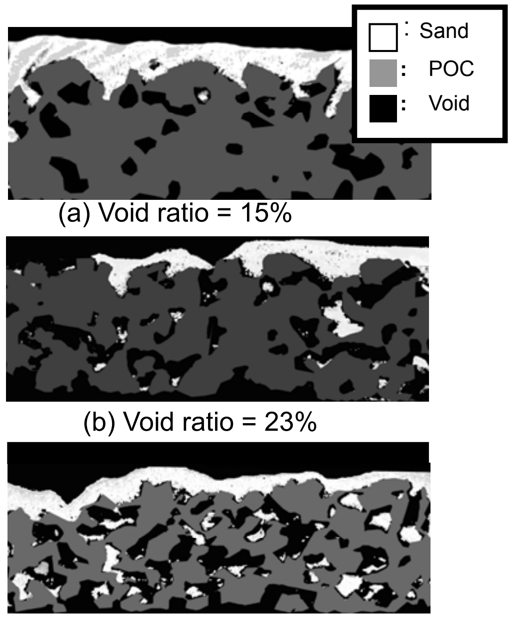
Fig.5 illustrates the relationship between void ratio and K_T. It can be seen that the K_T increases with ascending void ratio. The figure also illustrates that K_T improves with the increase in size of the aggregate. It is clearly visible in the figure that the permeability for grade G6 sample with 23% void ratio is higher than that of grade G7 sample with same void ratio.

(2) K_T of POC after the addition of sand

Fig.6 represents how the presence of sand in permeating water affects the coefficient of permeability (K_T) of POC with different void ratios and aggregate grades. It can be seen that permeability in all the cases decreases with the increase in amount of sand added. This goes to show that coefficient of permeability is bound to decline with time in the real situation also as the amount of foreign materials entering or depositing on the POC pavement increases progressively. Fig.7 displays the extent to which sand enters POC samples with different void ratios. The figure brings to light the fact that greater the value of the void ratio, greater is the quantity of sand entering the void. In Fig. 7(a) where the void ratio is 15%, the quantity of sand that has entered the voids is the minimum and most of the sand prevails on the surface of the sample as compared to that with void ratio 30% in Fig.7(c), where the sand has moved till the bottom most part of the sample. After the occurrence of clogging phenomenon, an attempt was made to see how effective would washing prove in restoring the coefficient of permeability of POC. For washing the silica sand that had entered the voids or deposited on the top of the sample, water pressure was applied from the top.

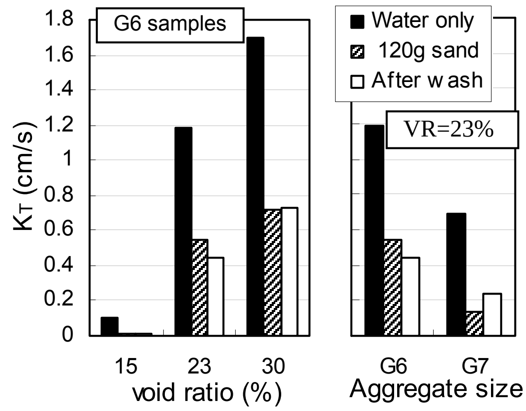
(3) Effect of washing on K_T

As illustrated in Fig.8(a), it was observed that after washing was carried out, K_T decreased for grade G6 samples with void ratios 15 and 23 %, but a slight increase though very insignificant, could be noticed in case of the samples with void ratio of 30%. The reason for this is that the larger amount of voids can facilitate the movement of sand from top till the bottom of the sample after which it goes out. Whereas, in case of lesser amount of voids, the sand gets stuck somewhere in the middle even when water pressure is applied during washing. In other words, the voids get clogged due to the inability of the sand entering in, to move till the bottom of the samples. A comparative study as shown in Fig.8 (b) was also made between samples of grades G6 and G7 with the same void ratio of 23%.In this case, it was noticed that washing helps to improve the coefficient of permeability of grade G7 aggregates



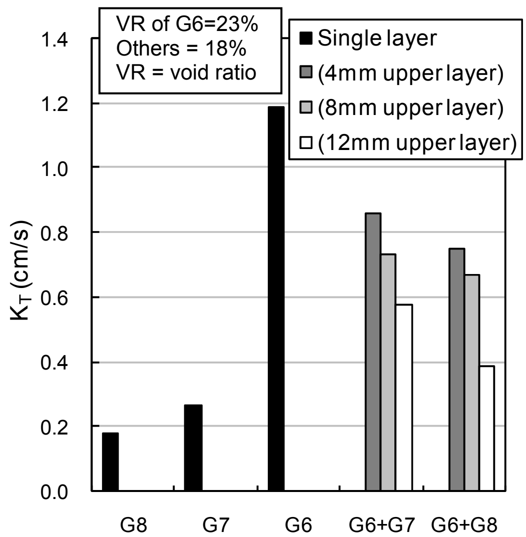
(a) Void ratio = 15%
(b) Void ratio = 23%
(c) Void ratio = 30%

Fig.7 State of sand inside voids of POC (Agg.size:G6)[3]



(a) Void ratio (b) Agg. size

Fig.8 Effect of washing on K_T [3]



Single and double layered samples

Fig.9 K_T under normal condition

as lesser amount of sand passes through to enter the voids of the sample. This makes it comparatively easier to recover the permeability by washing away the sand deposited on the surface of the sample.

An observation of washing becoming effective with the increasing value of void ratio or decreasing size of the aggregate was made through this experiment.

3.2 Second Experiment (Double layered POC)

As mentioned earlier, this experiment is a follow up experiment of the first experiment. Here a double layered POC is introduced in the effort to prevent the clogging of the voids of POC so that its permeability can be maintained. For that, the upper layer is designed to have smaller voids so that majority of the foreign materials can be stopped at the upper layer level itself.

(1) K_T of different samples on normal condition

Fig.9 represents the coefficient of permeability (K_T) of all the samples when only the normal tap water is allowed to pass through them. It can be seen here that though the coefficient of permeability of single layered G7 and G8 samples are low when their height is 50mm, it can be increased by reducing their thicknesses. It is made obvious by the figure where permeability in the double layered samples with lesser thicknesses of G7 and G8 aggregates in the upper layer are visibly greater than their single layers. Furthermore, the figure gives a clear picture of K_T reducing with the increasing thicknesses of the upper layers.

(2) Effect of addition of sand on K_T

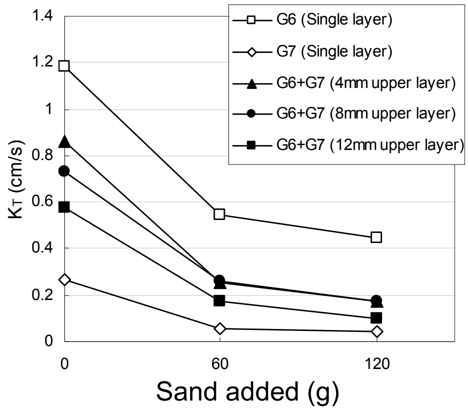
Fig.10 illustrates the reduction in the coefficient of permeability (K_T) of the samples by the addition of 60g each of silica sand in two batches, respectively.

Fig.10 (a) shows the effect on G6 and G7 single layered samples along with double layered samples of G6+G7 with three different thicknesses. Fig.10 (b) shows the effect on G6, G8 and G6+G8 samples. The upper layers of G7 and G8 grade aggregates are 4mm, 8mm and 12mm thick. It is clearly visible in the figures that in all the cases, the K_T reduces progressively. The trend is almost the same even if the values differ. Though it may seem obvious in mentioning that the K_T decreases more with the increase in amount of the sand added, but it would be worthwhile as it provides an image of the real situation. This indicates that over the time, the permeability of a POC pavement is bound to decline as the deposits of foreign materials on the surface or in the voids increase inevitably with time.

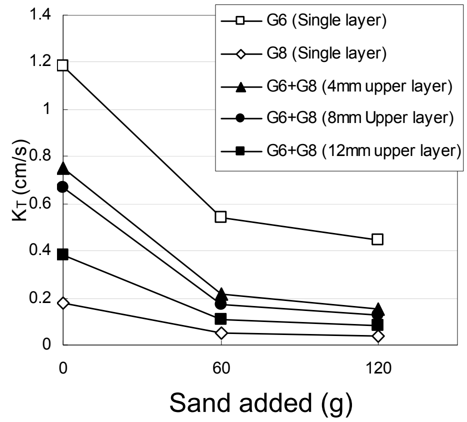
Therefore, it will be interesting to see what kind of impact washing has on the K_T of different samples in consideration. And should it work, it would provide a crucial breakthrough to the ever so bothersome clogging issue in single layered POC.

(3) Reduction of K_T by the addition of sand

Fig.11 portrays the percentage reduction of K_T after the addition of sand. It can be observed that the decrease is the maximum in case of G8 and G6+G8 samples. It is because most of the sand gets deposited on the surface unlike G6 and G7 samples where comparatively more of them enter through the voids in the process facilitating the permeability to better extent.

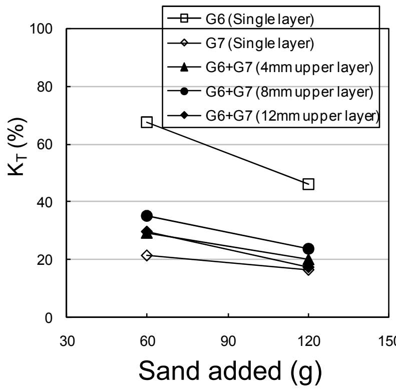


(a) For single and G7 upper layers

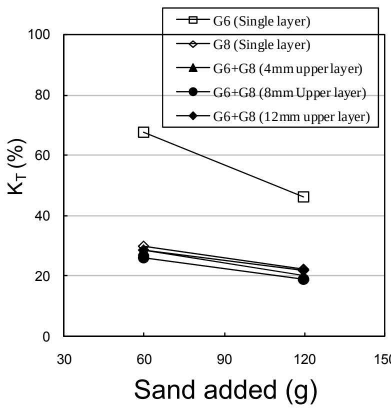


(b) Single and G8 upper layers

Fig.10 Effect of addition of sand on K_T



(a) Single and G7 upper layers



(b) Single and G8 upper layers

Fig.11 Percentage reduction of K_T by addition of sand

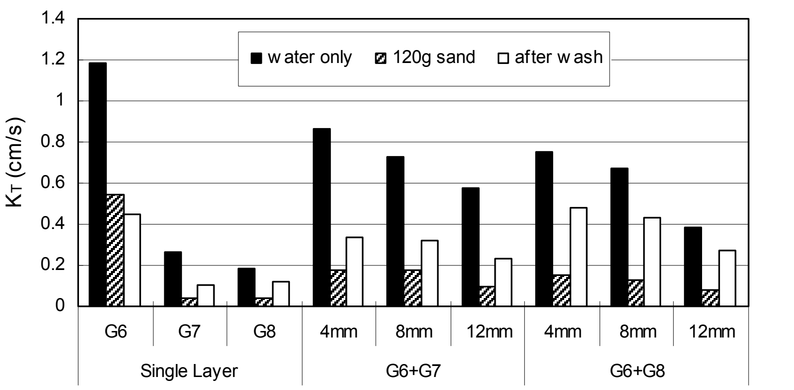


Fig.12 Effect of washing on K_T of single and double layered POC

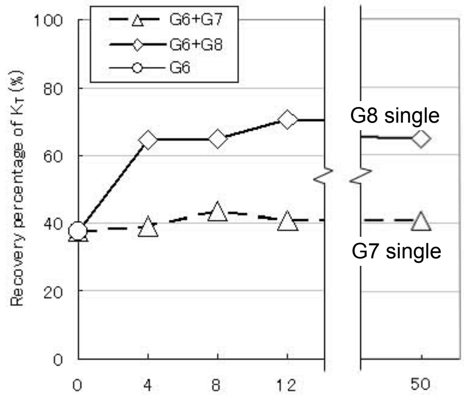


Fig.13 Recovery of K_T on washing

(4) Effect of washing on K_T

Fig.12 demonstrates the effect of washing on the K_T of all the samples in consideration. A look at the figure can give us a fairly good idea of the trend followed by the K_T of different samples with the changing conditions. It can be seen that there is in fact a significant improvement in K_T for all the samples except for the grade G6 sample. G8 and G6+G8 samples show noteworthy as well as consistent recovery of K_T on washing.

Noticeable restoration is also visible in case of G7 and G6+G7 samples. This is because of the fact that with the smaller sizes of the aggregate, the amount of sand entering into the voids is lesser as the voids are smaller than that of bigger size aggregates even though the void ratios are the same. Moreover, majority of the sand entering from the smaller voids of G8 aggregate upper layer should be able to pass through the bigger voids of G6 aggregate layer underneath. And that is exactly what makes it possible to recover back the K_T to a greater extent as the sand deposited on the surface of the samples can be either washed away with the water pressure or pushed through the under layer.

On the other hand, comparatively more amount of sand can enter through the voids of G7 and G6 +G7 samples because of which the probability of under layer getting clogged becomes more.

This result is in keeping with the philosophy behind advocating the double layered POC which is to try and restrain the majority of the foreign materials from entering into the voids so that they can be washed away to restore and maintain the permeability. Further experiments with the combinations of different thicknesses and void ratios of the layers will have to be conducted to confirm the mechanism.

(5) Recovery of K_T on washing

Fig.13 represents the recovery percentage of coefficient of permeability of double layered POC. This figure supplements Fig.12 by giving clearer image of how the K_T changes after the washing procedure is applied for the samples in consideration. A visibly clear gap in the recovery percentages of the K_T exists between G7 and G8 aggregate double and single layer samples. As mentioned earlier also, G8 samples display a much better K_T restoration tendency than the G7 samples.

4. CONCLUSION

This paper includes two experimental studies. The first experiment was carried out to find the effect of clogging on the coefficient of permeability (K_T) of single layered POC followed by a second one on double layered POC. The second experiment is an effort to see if clogging issue could be addressed with a double layered POC.

It can be inferred from the first experiment that clogging reduces the coefficient of permeability of POC. It reduces more with the increasing amount of added sand in water passing through it. Washing reduces the K_T of G6 aggregate sample with void ratio of 23%. A slight but insignificant increase in the G6 samples with 30% void ratio was noticed. Interestingly, better recovery in K_T could be noticed in case of G7 grade aggregate samples with 23% void ratio.

In the second experiment, it was observed that G8 and G6+G8 samples provided very good restoration of K_T on washing. It was also noticed that G7 and G6+G7 samples performed fairly well in the restoration efforts. However, G8 samples stood out with much higher recovery percentage of up to 70% as opposed to G7 samples which was around 40%. This justifies the envisioned purpose of the double layered POC which is to restrain the foreign materials from entering the voids of POC at the surface level of smaller sized aggregates with smaller sized voids. This way, clogging of voids can be prevented and at the same time, the debris at the surface can be washed off to restore the permeability of porous concrete.

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