コンクリート工学年次論文報告集, Vol. 20, No. 2, 1998

論文 Permeability of No-Fines Concrete

Abderrazak ZOUAGHI [*1], Takao NAKAZAWA [*2], Fujio IMAI [*2] and Nario SHINISHI [*2]

ABSTRACT: The permeability of no-fines concrete consisting solely of Portland cement, water and uniform-sized aggregate was investigated. Three basic coarse aggregate-cement ratios by volume (A/C = 6, 8 and 12) were used to mix each of the three aggregate types of various gradations (Crushed limestone: 6 gradations, Pumice: 3, and Scoria: 3). A total of 260 tests was performed using a constant head permeameter. Effects of factors such as: aggregate type, gradation, shape, bound limit, void content, paste content and water-cement ratio on permeability of no-fines concrete as well as specimen length and testing procedures are reported.

KEYWORDS: no-fines concrete, permeability, void content, aggregate gradation, aggregate shape, aggregate type, paste content, specimen length, constant head test, falling head test.

1. INTRODUCTION:

No-fines concrete consisting solely of Portland cement, water and uniform-sized aggregate is neither as strong nor as tough as conventional concrete nor as steel, so why there has been growing interest in its use since 1852[1]. There are a number of reasons. First no-fines concrete possesses a high capability of draining water[2-4]. The second reason for its use is the lower unit weight, generally 70 % that of conventional concrete, and the ease with which structural no-fines concrete can be finished. The third reason for the increasing use of no-fines concrete is that it is usually the cheapest and most readily available on the job. Recently, in Japan it is used as an ecological material (Environmentally friendly concrete). Throughout the country, researchers have doubled efforts to evaluate porous concrete, with the aim of establishing design specifications and developing pertinent design methodologies compatible with climatic conditions, materials availability, and construction procedures [4-12].

Over the years, a wide variety of empirical equations and models have been presented for estimating the coefficient of permeability of porous media. Still the only tool for predicting permeability of cemented granular material found in the literature is **Table 1** from Lovering and Cedergren [13].

Indeed by 1976, no quantitative data on the permeability of no-fines concrete was reported[1]. Despite that highway research laboratories have designed several perimeters to determine the coefficient of water permeability of the subbases under conditions found in highways[14], at present, there is no standard laboratory test for permeability of granular material [3]. The common used permeameter is the constant head permeameter. In Japan, investigators have

Table 1 Laboratory permeabilities of untreated and treated asphalt-stabilized open-graded aggregates

Aggregate size range	Permeability (cm/s) Untreated	Permeability (cm/s) bound with 2% asphalt
38.1 to 25.4 mm	49.40	42.30
19.1 to 9.5 mm	13.40	12.34
4.75 to 2.36 mm	2.82	2.12

Lovering and Cedergren (1962)

[*1] Graduate School of Miyazaki University, Graduate student, Member of JCI

[*2] Dept. of Civil and Environmental Engineering, Miyazaki University, DR, Member of JCI

used it according to JIS A 1218. The specimen dimensions and head loss varied from one investigator to an other. Use of cylindrical, generally 10 cm of diameter[5-10], and prismatic specimens 10.5x16.5x6 cm was reported[11]. Head losses were also variable, from few centimeters up to 30 cm. Overseas the specimens were generally cylindrical with a diameter of 15.2 cm. Herein results of 260 laboratory experimental tests on permeability of no-fines concrete using a constant head and falling head tests are presented. This study relates factors such as: aggregate type, shape and gradation, void content, paste content and water-cement ratio to permeability of no-fines concrete. Effects of specimen length and testing procedures on permeability are also reported.

2. EXPERIMENTALWORK

2.1 PREPARATION OF SPECIMENS

Ordinary Portland cement (specific gravity of 3.15 and blaine of 3290 cm^2/g) was used to make several mixes with three basic aggregate cement ratios by volume (A/C= 6, 8, and 12). Six different coarse aggregate gradations of crushed limestone (CL), 3 of Pumice ((P) a light-colored vesicular glassy rock having the composition of rhyoltie) and 3 of Scoria ((S) a bomb-size pyroclast that is irregular in form and very vesicular) were used.

The authors have reported that for each A/C, initial tests should be made to indicate the optimum water-cement ratio [10]. This optimum is then adopted for each A/C. However, because this is time consuming and strength is not the primary requirement in the present work, a basic water-cement ratio of 25% was adopted for all aggregate gradation of different types.

The mixing procedure and specimens casting were the same as that in our previous work[10]. Briefly, the volume of aggregate was maintained constant to $1 m^3$ and the cement factor was changed. The aggregates and 1/4 of the effective water were introduced first into a pan-type forced circulating mixer of 50 liters of capacity. The cement was added after 30 seconds. One minute later, the remaining water was added and the mixing continued for 30 seconds. The mixer was stopped for 20 seconds and then restarted for 30 seconds. After discharging, the consistency inspection was carried out by a visual examination and a bucket with holes described elsewhere[4]. The concrete was placed in the molds in layers of about 10 cm and light hand rammed.

2.2 TESTINGOF SPECIMENS

Three series of specimens were tested for permeability. First one, specimens with diameter 10 cm and length of 10 cm. Second and third are of variable lengths and diameters made with scoria (S 5-10) and crushed limestone (CL 20-40) respectively. The lengths were, 1.0, 1.5, and 2.0 times that of the diameter. For scoria, the diameters were 5.6, 7.5, 10.5, 14.7, and 20.2 cm whereas 14.7 and 20.2 cm for crushed limestone.

The void content accounts for the total volume through which water can flow inside the sample and was assumed to be a very important factor in the experiments. Its values were calculated following the procedure proposed by eco-concrete research committee [12].

The constant head permeability test procedure determines the permeability of no-fines concrete by maintaining a constant head (h) on the sample surface and measuring the amount of water collected for a known quantity of time (Δt). The permeability can then be calculated using the equation

$$k_{c15} = (H/h) \bullet (Q/(A \bullet \Delta t)) \bullet \eta_T/\eta_{15} \qquad (1)$$

where,

k_{c15} = coefficient of permeability (cm/s), from constant head test;
H = flow path length or sample height (cm);
h = constant water head (cm);
Q = flow quantity (cm^3);
A = flow path area or sample area (cm^2);
Δt = quantity of time (s);
η_T/η_{15} = relative viscosity of the water at temperature T (°C).

The falling head permeability test determines the permeability of no-fines concrete by measuring the time required for the water head to drop from high level (h_0) to a low level (h_1). Herein h_0-h_1=100 mm. The permeability is then calculated using the equation

$$k_f = (a/A) \bullet H/\Delta t \bullet \log_e \bullet (h_0 / h_1) \qquad (2)$$

where,

k_f = coefficient of permeability (cm/s), from falling head test;
H = flow path length or sample height (cm);
Δt = time required for the water head to drop from high level (h_0) to a low level (h_1);
a/A = ratio of the area of the stand pipe to that of the sample; and
h_0, h_1 = water levels.

3. RESULTS AND DISCUSSION

3.1 EFFECTS OF MIXTURE PROPORTION ON PERMEABILITY

Void content of six hundred specimens from 40 different mixture proportions were measured using two methods. In this experiment the average within-batch variation for unit weight was 2.5 % for crushed limestone and scoria but 2.6 % for pumice.

Fig. 1 illustrates a relationship between continuous void content calculated by volume method (Cv_V) and that by weight method (Cv_W). Cv_W is bigger than Cv_V. The weight method supposes that paste is uniformly coating the aggregates. However it is clear from this figure and a cross-section cutting of specimens that paste is not distributed uniformly throughout the mass of no-fines concrete. Therefore it is obvious that the phases of the honeycomb structure are neither homogeneously distributed with respect to each other nor are they themselves homogeneous. The cement paste coating the aggregate is thicker in some parts and thinner in others.

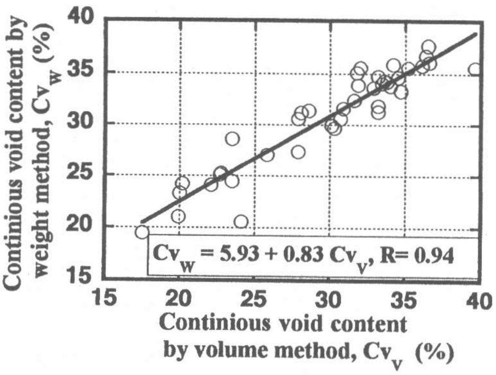

Fig. 1 Relationship between continuous void content calculated by volume method and that by weight method

Fig. 2 reports that an additional of 100 kg/m^3 of cement paste reduces the continuous void content on no-fines concrete, made with various aggregate types of two different gradations, by about 4.6 %.

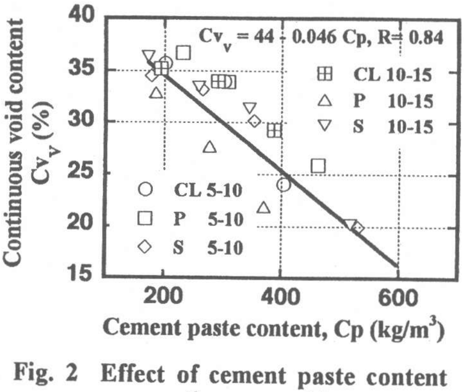

Fig. 2 Effect of cement paste content on continuous void content

Fig. 3 depicts a relationship between permeability of no-fines concrete made with various aggregate types and continuous void content calculated by volume method. Permeability increases with continuous void content. Moreover for the same void content, example: $Cv_V \approx 34\%$, permeability might vary from one concrete to an other. This is thought to be related to texture differences of no-fines concrete. Also permeability does not depend on the aggregate type. Thus, in case where the permeability is the required property, these volcanic aggregates may be successfully used for production of no-fines concrete.

Fig. 4 shows the effect of compaction degree and methods on permeability. It shows that copmaction methods affect the total void content (T_{V_V}) and do not necessary influence the continuous void content. It comes to confirm what the authors have stressed above. The reduction of compaction effort, bounding material or change in aggregate's bound limit[10] of a given concrete might modify the size of the pores and their interconnection within the mass of no-fines concrete and hence an even greater percentage change in permeability.

Fig. 5 represents the effect of aggregate gradation on permeability. Generally the permeability increases with increment of aggregate gradation and the drop of permeability for CL 20-25 mm could be due to its shape. **Table 2** shows measured results of sphericity that characterizes the shape of aggregates. It shows that CL 20-25 has a disc-shaped whereas that CL 10-15, CL 15-20, and CL 20-40 had spherical one. Some similar results are reported elsewhere[7].

Table 2 Results of aggregate shape

Limestone	Eq.d. (mm)*	Sphericity	Shape
CL 5-10	8.49	0.664	Disc-shaped
CL 10-15	14.30	0.703	Spherical
CL 15-20	18.01	0.710	Spherical
CL 20-25	21.70	0.677	Disc-shaped
CL 20-40	26.00	0.694	Spherical

* Eq.d. = equivalent spherical diameter

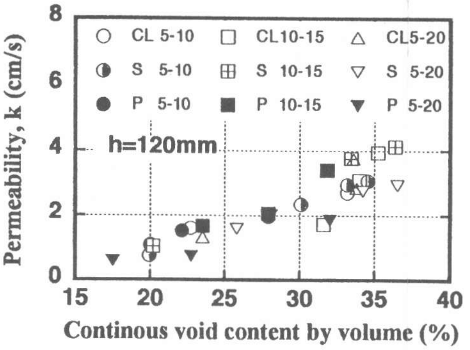

Fig. 3 **Relationship between permeability and aggregate type**

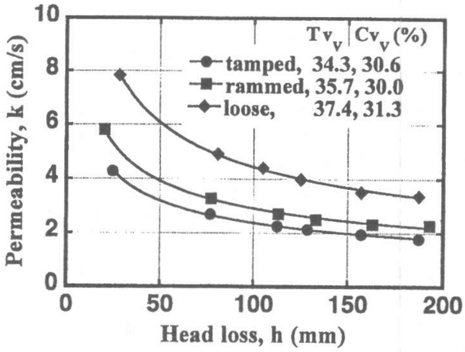

Fig. 4 **Effect of compaction method on permeability**

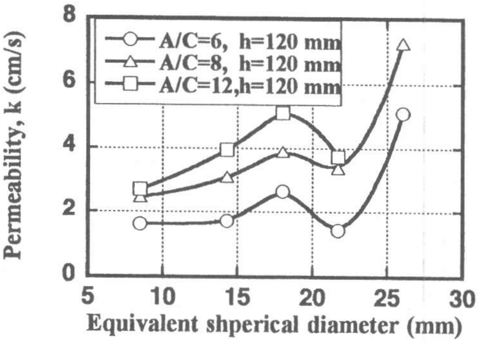

Fig. 5 **Influence of aggregate gradation on permeability**

3.2 INFLUENCE OF MEASUREMENT PROCEDURES ON PERMEABILITY

Fig. 6 represents the influence of the variation of head loss and water-cement ratio on permeability. Clearly permeability increases with any increment of aggregate-cement ratio whatever the head loss is. Variation of head loss influences significantly the permeability measurement. On the basis of these results it is recommended that laboratory permeability be performed at head loss of 120 mm since at this level it was ease to maintain a constant water flow. In **Fig. 6** the effect of water-cement ratio on permeability is illustrated by 2 examples (A/C = 8 and 12). Cement pastes with distinct W/C possess different rheological properties. Cement paste with higher W/C is more fluid and flows off the aggregate particles to fill voids in the lower part of the specimens and hence reduces its permeability. **Fig 6** clarifies that reduction on the water-cement ratio might increase the permeability sharply. At a medium cement factor (A/C=8) a reduction of water-cement ratio by 15 % increases the permeability by about 0.5 cm/s however at a lower cement factor a reduction of 26 % increases the permeability by about 2 cm/s.

Example of test results from the two methods used to measure the permeability is plotted in **Fig. 7**. Throughout the experiments falling head method was rapidly done and offered higher permeability coefficient than constant head one that is time and energy consuming. It was reported that the variation of the permeability, done on sample of asphalt treated permeable material, from the two testing procedures may be due to the difference in the way water is introduced into the sample during testing[15].

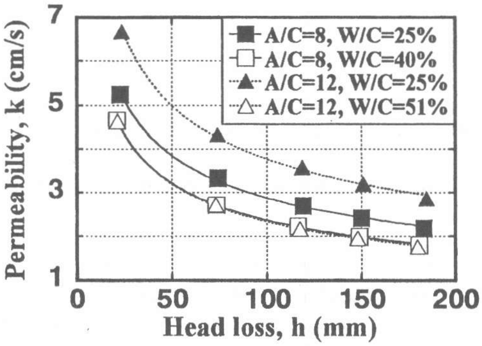

Fig. 6 Effect of head loss and water-cement ratio variation on permeability

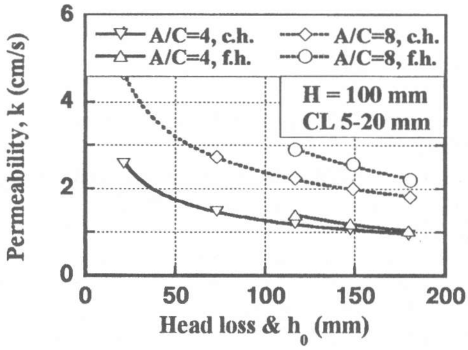

Fig. 7 Comparison between constant head loss test and falling head test

3.3 EFFECT OF SPECIMEN LENGTH ON PERMEABILITY

Several specimens of various mixture proportions with different geometry characteristics were tested for permeability at a head loss of 120 mm. **Fig. 8** summarizes a part of the results.

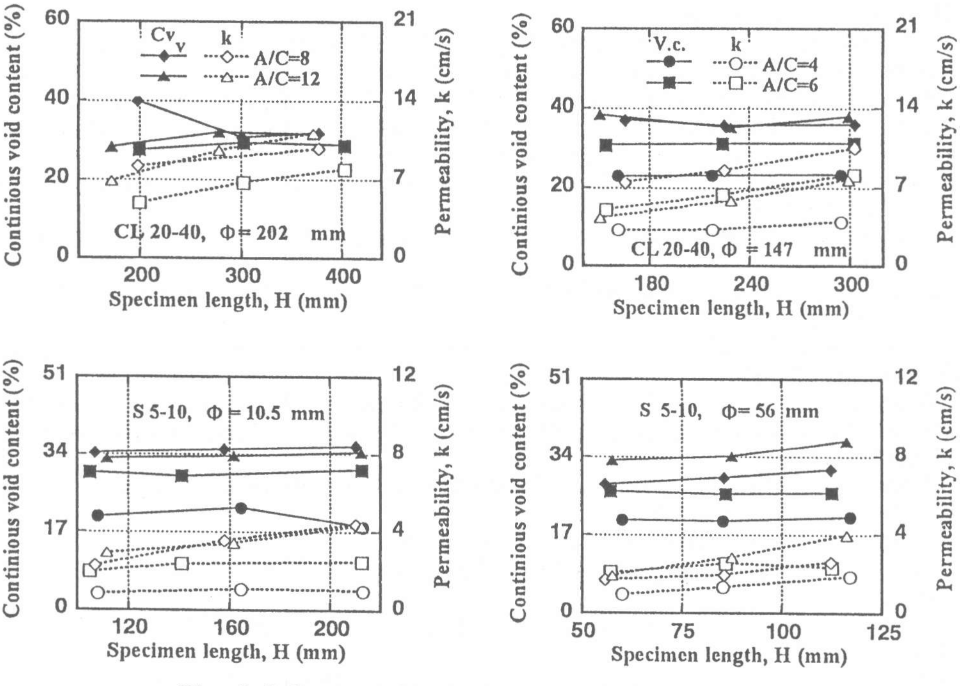

Fig. 8 Influence of specimen length on permeability

Fig. 8 reports effect of specimen length variation on permeability. Unlike samples of soils or rocks, permeability of specimens of concrete, with both gradations S 5-10 and CL 20-40 mm and various cross sections area, tested at a head loss of 120 mm depends on the specimen length. The later coupled with the variation of continuous void content from one series to an other reflect the high anisotropy of no-fines concrete. Specimens from the same concrete do not have the same internal structure (pore size distribution) even if they are cast in molds of same geometry.

4. CONCLUSIONS

A total of 260 tests were performed to measure the permeability of no-fines concrete and afforded to the following results:
(1) Void determination should be made using volume method since the geometry of the matrix of no-fines concrete is concerned.
(2) The permeability is independent of the coarse aggregate type.
(3) Factors such as aggregate gradation, shape, bound limit, paste content, and water-cement ratio influence significantly the texture of no-fines concrete and hence its permeability.
(4) The method of measurement of permeability of no-fines concrete influences its permeability coefficient. Falling head test is fast, simple and can be used for comparative studies.
(5) Unlike samples of soils or rocks, the permeability of no fines concrete depends on specimen's length. Specimen of ϕ=15 x 15 cm are easy to manipulate with and therefore recommended.

REFERENCES

1. Molhotra, V. M., "No-Fines Concrete — Its Properties and Applications," J. Of ACI, Vol.73, Nov., 1976, pp.628-644.
2. Torbjorn, J. Larsen. and Jamshid, M. Armaghani., "Draincrete in Pavement Rehabilitation," J. of TRR, No.1110, 1987, pp75-80.
3. Kazamierowski, T. J., Bradbury, A. and Hajek J., "Field Evaluation of Various Types of Open-Graded Drainage Layers," J. of TRR, No.1434, 1993, pp.29-36.
4. Tamai, M., "Water Permeable Concrete," JCI, Vol.32, No.7, Jul., 1994, pp.134-138.
5. Tamai, M. and Kawai, A., "Changes of Marine Eplithic Organisms on the Concrete with Continuous Voids," J. of ..., JSCE, No.452/II-20, Aug., 1992, pp.81-90.
6. Matsukawa, T. and et al., "Void Conditions of Planted Concrete," Proceedings of JCI, Vol.18, No.1, 1996, pp.999-1004.
7. Tamai, M., "Water Permeability of Hardened Materials with Continuous Voids," CAJ review 1988, pp.446-449.
8. Ohtomo, T. and et al., "Development of Permeable Concrete," Proceedings of JCA, No.45, 1991, pp.750-755.
9. Takahashi T. and et al., "Development of Permeable concrete," Proceedings of JCI, Vol.14, No.1, 1992, pp.351.356.
10. Zouaghi, A., Nakazawa, T., Shinnishi, N., "Effect of Aggregate shape and Mixture Proportion on Permeability and Strength of Porous Concrete, " Proceedings of JCA, No.51, 1997, pp.882-887.
11. Matsuo, S. and et al., "Properties of Permeable Concrete with Foaming Agent," Proceedings of JCA, No.46, 1992, pp.948-953.
12. Report of the Eco-concrete research committee, Nov., 1995, pp.53-58.
13. Harry R. C., "Drainage of Highway and Airfield Pavements," John Wiley & sons Inc., 1974, pp.186.
14. E. S. Barber and C. L. Sawyer, "Highway Subdrainage" PUBLIC ROADS, Vol.26, No.12, Feb., 1952, pp.251-268.
15. Haiping Z. et al., "Determination of Free-Draining Base Materials Properties," J. of TRR, No.1425, 1993, pp.54-63