Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 53(8) (2021) 767-770
DOI: 10.22060/ceej.2020.17978.6726

Effects of Concrete Constituent Materials on the Penetration of Surface Water

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ABSTRACT: Concrete is one of the widely used materials in hydraulic structures. The permeability of these structures is considered to be one of the most important factors. Therefore, in this paper, the effects of aggregates, cement paste, transition zones, and concrete surface strength, on the penetration of surface water into the concrete are presented. For this study, 150 mm concrete cubes containing granite, andesite, siliceous, limestone, marble, and tuff aggregates were prepared. These specimens also contained type 2 Portland cement, silica fume, fly-ash, zeolite, and limestone powder. These admixtures replaced 10% of the cement content. While the "cylindrical chamber" was used for the permeability measurement, the "Twist-off" method was used to estimate the surface strength of the concrete specimens. Regression analysis of the permeability readings of the parent rocks, cement paste, interfacial transition zone length, and concrete surface strength revealed that the penetrated water volume into the concrete specimens could be predicted, using the proposed regression equation. It was also observed that, compared with other considered parameters, the cement paste, and concrete surface strength had the highest and lowest impact on the concrete permeability, respectively.

Review History:

Received: Feb. 21, 2020
Revised: Jun. 28, 2020
Accepted: Jul. 13, 2020
Available Online: Aug. 21, 2020

Keywords:

Concrete permeability
Aggregate and cement paste
Regression analysis
Twist-off
Cylindrical chamber

1. INTRODUCTION

Concrete structures, such as dams, channels, and cooling towers should have sufficient durability to provide satisfactory service, during their design lives. Permeability is one of the most deciding factors in determining concrete durability. For this reason, many researchers have focused on studying concrete permeability. Aggregates, cement paste, and the boundary between the two appear to have the highest influence on the concrete permeability. Since the water penetration occurs from the concrete surface, it seems fair to consider the correlation between the concrete permeability and its surface strength. For this reason, a regression analysis was applied in this investigation to evaluate the effect of the mentioned parameters on the permeability of concretes, containing different types of aggregates and admixtures. In this paper, "cylindrical chamber" [1, 2] and "Twist-off" [3, 4] methods were used to measure concrete permeability and surface strength, respectively. It is worth mentioning that these methods can be undertaken in the laboratory and on-site, which is the most significant benefit of these methods over the other available ones.

2. METHODOLOGY

In this paper, a total of 60 cubic concrete specimens, containing different types of aggregates and admixtures were prepared for "cylindrical chamber" and "Twist-off" tests. In addition, the permeability of the corresponding cement pastes and parent rocks used for concrete preparation were also measured. For this purpose, granites, andesite, siliceous, limestone, marble, and tuff parent rocks were crushed in a crusher to produce aggregates for concrete mixes. The control concrete specimen was made of type 2 Portland cement. Ten percent of the cement mass was replaced by silica fume, fly-ash, zeolite, and limestone powder for other concrete mixtures. The permeability and surface strength of the concrete cubes were measured using "cylindrical chamber" and "Twist-off", methods, respectively.

For the "cylindrical chamber" test, having thoroughly cleaned the concrete surface, the metallic base plate is bonded to the surface of the testing area, using an epoxy resin adhesive. After the hardening of the epoxy resin, the chamber is filled with water. Then the required pressure is applied to the water in the chamber, by turning the pressure handle and at the required time intervals, the volume of penetrated water is calculated using the readings of the micrometer, attached to the apparatus. The "cylindrical chamber" tests which was performed on some concrete specimens are shown in Fig. 1.

For the "Twist-off" test, as shown in Fig. 2, the surface of the concrete specimen was cleaned thoroughly before the test. Then, a metallic probe of 40 or 50 mm dimensions was glued to the specimen surface using an epoxy resin adhesive. After hardening of the epoxy resin, an ordinary torque meter was used to measure the twisting moment, required to

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Fig. 1. Concrete specimens prepared for "cylindrical chamber" tests

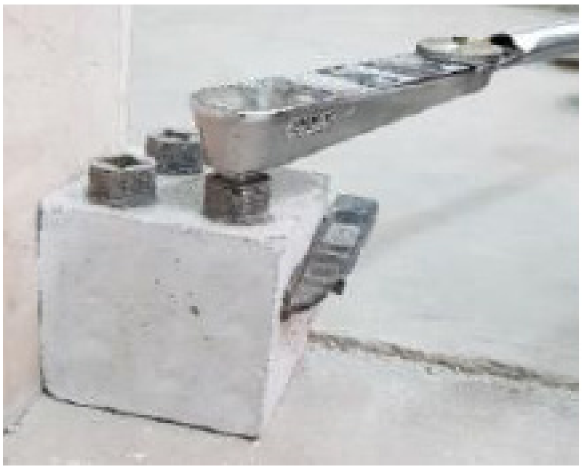


Fig. 2. "Twist-off" test

separate the metallic probe from the specimen surface. The separation surface should be visually inspected to make sure that the metallic probe is detached from the concrete surface, not from the epoxy resin adhesive. Surface strength obtained from the "Twist-off" method, is calculated using Eq. (1):

$$\tau = \frac{T \times r}{J} \quad (1)$$

In the above equation, ô is the surface strength (MPa), T is the twisting moment required to separate the metallic probe from the specimen surface (N.mm), r is the radius of the metallic probe (mm), and J is the polar moment of inertia of the metallic probe (mm^4).

To evaluate the effect of concrete constituent materials on their permeability, a 30 mm slice was cut off from the concrete specimen, using a concrete saw. Therefore, this saw-cut surface was used for the permeability test. This surface was also photographed before the tests, to measure the surface area of the aggregates and cement paste and the length of the interfacial transition zone (ITZ). For this purpose, the boundary between the aggregates and cement paste was marked with curves. This procedure which was performed using image analysis software is shown in Fig. 3.

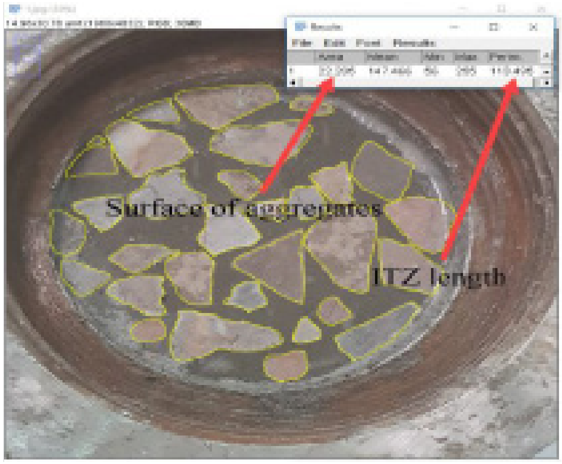


Fig. 3. Measuring the surface area of the aggregates and ITZ length

It should be noted that the permeability and surface strength of all concrete cubes were measured at the age of 28 days.

3. RESULTS AND DISCUSSIONS

A regression analysis was applied to evaluate the effect of the mentioned parameters on concrete permeability. For this purpose, Eq. (2) has been proposed as follows:

$$V = C_1 \frac{S_a}{S_b} V_a + C_2 \frac{S_p}{S_b} V_p + C_3 L + C_4 F_s + C_5 = C_1 C_a + C_2 C_p + C_3 L + C_4 F_s + C_5 \quad (2)$$

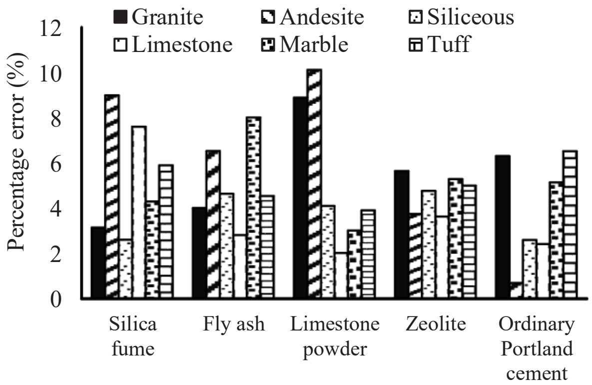
In the above equation, V is the penetrated water volume (ml), S is the surface (cm^2), L is the length of the boundary between the aggregates and cement paste (cm), F_s is the surface strength (MPa), and C_i is the constant coefficient for i^{th} variable in the regression equation. The subscripts a, p, and b represent the aggregates, cement paste, and base plate, respectively. C_a and C_p are also the contribution of the aggregates, and cement paste to the penetrated water volume, respectively. It should be noted that a backward scheme was adopted for the regression analysis.

The standardized equations obtained from the regression analysis are formulated as below:

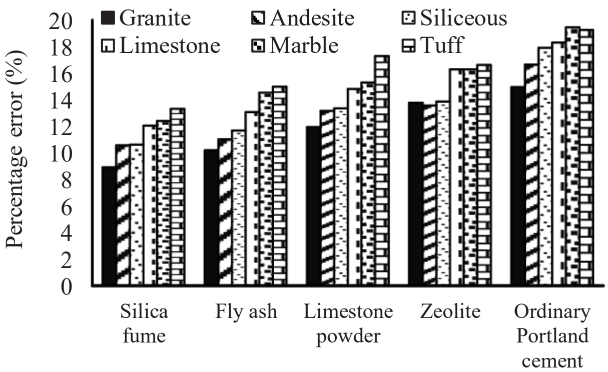
$$\overline{V} = 0.816\overline{C}_a + 1.199\overline{C}_p + 0.435\overline{L} + 0.088\overline{F}_s \quad (3)$$

$$\overline{V} = 0.743\overline{C}_a + 1.174\overline{C}_p + 0.454\overline{L} \quad (4)$$

The standardized variables are used in the above equations. It can be seen from Eq. (3) that the cement paste is the most effective factor, which controls concrete permeability. Also, it can be seen from Eq. (3) that surface strength doesn't contribute significantly to concrete permeability. This is the reason why this parameter has been excluded from the model in the second step of the regression analysis. Aggregates and ITZ ranked second and third, respectively, considering the



(a) Absolute percentage error for estimating the penetrated water volume into the concrete specimens, considering the variables C_a, C_p, F_s, and L.



(b) Absolute percentage error for estimating the penetrated water volume into the concrete specimens, considering the variables C_a, C_p, and L.

Fig. 4. Absolute percentage error for estimating the penetrated water volume into the concrete specimens

factors with higher influence on concrete permeability in Eqs. (3) and (4). Adjusted R^2 were calculated as 0.911 and 0.909 for Eqs. (3) and (4), respectively. So, the penetrated water volume into the concrete specimens can be estimated with high accuracy, considering the mentioned variables.

The percentage errors for estimating the penetrated water volumes, calculated from Eqs. (3) and (4) are shown in Fig. (4). This Figure shows that the average percentage errors for the calculation of the penetrated water volume obtained from Eqs. (3) and (4) are 4.89 and 14.21%, respectively. It is seen that the average absolute error has increased by 9.32% when the surface strength is eliminated from the regression equation.

4. CONCLUSION

In this paper, the effect of the concrete constituent materials, including aggregate, cement paste, ITZ, and surface strength on concrete water permeability was investigated using regression analysis. For this purpose, concrete specimens containing different types of admixtures and aggregates were prepared. The results showed that the penetrated water volume into the concrete specimens can be predicted with high accuracy, considering the mentioned variables. It was also observed that cement paste is the most effective factor in concrete permeability. Also, it was seen that surface strength doesn't contribute significantly to concrete permeability. Therefore, having excluded the surface strength variable from the regression equation, the average absolute error increased by 9.32%. Aggregates and ITZ ranked second and third, respectively, considering the factors with higher influence on concrete permeability.

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HOW TO CITE THIS ARTICLE

M. Naderi, A. R. Kaboudan, Effects of Concrete Constituent Materials on the Penetration of Surface Water, Amirkabir J. Civil Eng., 53(8) (2021) 767-770.

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