- Technical Paper -

INVESTIGATION ON CORRELATION BETWEEN SURFACE WATER ABSORPTION TEST AND JSCE SORPTIVITY TEST

Raphael N. UWAZURUONYE*1 and Akira HOSODA*2

ABSTRACT

This paper presents the correlative assessment of 2018 JSCE-G 582 test standard and Surface Water Absorption Test (SWAT) for five different concrete mix proportions of three cement types. New indices for the two test methods (coefficient of water absorption) were applied and found to be correlated. The cumulative water absorption from SWAT and depth of penetration from JSCE-G 582 also showed a good correlation. The findings revealed that any of the two indices from SWAT could effectively be applied to evaluate concrete's resistance to water penetration.

Keywords: SWAT, coefficient of surface water absorption, JSCE sorptivity test, quality evaluation

1. INTRODUCTION

It is a general knowledge that the durability of concrete depends largely on the resistance of concrete against the penetration of both liquid and gaseous deleterious substances[1]. The water absorption resistance of concrete has been the most common and the simplest index for durability assessment.

It has long been confirmed that the short-term water penetration depth of concrete has an approximately linear relationship with the square root of immersion time. Although many methods and test standards have previously been utilized to evaluate the water penetration rate of concrete, most of them are destructive and remain inapplicable in field investigations, evaluations and grading of RC structures. Recently in 2018, JSCE G-582 was established as a test standard for determining the water penetration rate coefficient of concrete subjected to water in short-term. This paper evaluates the relationship between the experimental results of JSCE-G 582 test standard and the results of Surface Water Absorption Test (SWAT) method.

The coefficient of surface water absorption (CSWA), for quality evaluation by SWAT, is newly introduced in this study and compared with JSCE-G 582 test results. Furthermore, conventional SWAT indices like p_{600} and total absorption amount are also compared with JSCE-G 582 test results. In this paper, the applicability of SWAT is evaluated for evaluating water absorption resistance in short time.

2. INVESTIGATION METHODS

2.1 JSCE-G 582 Test Standard

The Japan Society of Civil Engineers (JSCE) sorptivity test standard for determining water penetration rate coefficients of concrete subjected to water in short time was established in 2018 as JSCE-G 582 [2]. The outline of the steps for the sample preparations are as follows:

a) Prepare cylindrical concrete specimen of ϕ100 mm × 200 mm height.
b) After curing (curing condition should be the same with the actual structure under investigation), cut off 25 mm thickness from the face of the form-finished-surface with dry type concrete cutter.
c) Dry specimens in a controlled chamber at a temperature of 40 ± 2°C and relative humidity of 30 ± 5% for 28 days. Or dry in a controlled chamber at a temperature of 20 ± 2°C and relative humidity of 60 ± 5% for 91 days. If drying is done at 40 ± 2°C and 30 ± 5% R.H., drying can be stopped when a 24-hour mass change is less than 0.1%.
d) Allow specimens to return to room temperature by natural heat loss for a minimum of 1 hour and store in a closed container for 24 hours.
e) Seal the lateral sides of the specimen and the surface that was not exposed by cutting with water penetration resistant material such as aluminum tape or foil and epoxy resin. Allow the epoxy resin to dry before starting the test.

The standard also outlined the test procedures as follows:

f) Tap water of 20 ± 2°C temperature shall be used. In order to stabilize the temperature of the water and to expel the dissolved air in water after collecting it from the tap, store water in a controlled environment of 20 ± 2°C temperature for 24 hours or more.
g) Make a 10 mm mark from the bottom of the specimen and carefully place 5 mm height spacers (to raise the specimen from the bottom of the container) on the container. Ensure that the total contact area between the spacers and the specimen does not exceed 10% of the surface area of the specimen.
h) Pour the stabilized water into the container up to the

*1 Ph.D. Candidate, Graduate School of Urban Innovation, Yokohama National University, JCI Student Member
*2 Professor, Faculty of Urban Innovation, Yokohama National University, D.Eng., JCI Member

marked 10 mm height and carefully immerse the specimen. The immersion period is 48 hours and the measurements shall be taken at 5 hours, 24 hours and 48 hours respectively. For each measurement time, a minimum of 3 samples shall be withdrawn and utilized.

i) Split specimen into two halves and measure the depth of penetration immediately after withdrawal from water. Measurement shall be in 0.5 mm units with a vernier caliper or a straight metal rule from one half of the split specimen. A minimum of 5 measurements L1 – L5 shall be recorded for each specimen and the distance from the sealed edge of the specimen shall not be less than 20 mm. Moisture penetration depth shall be determined by spraying a colour-differentiating water detector that conforms with NDIS 3423 specification.

The moisture penetration rate coefficient, A, which is the depth of water penetration obtained during the immersion of 5 to 48 hours is calculated thus:

$$A = \frac{\sum_{n=1}^{n}(\sqrt{t_i} - \overline{\sqrt{t}}).(L_i - \bar{L})}{\sum_{n=1}^{n}(\sqrt{t_i} - \overline{\sqrt{t}})^2} \quad (1)$$

Where A: moisture penetration rate coefficient (mm/$\sqrt{hr}$), n: number of data, $\sqrt{t_i}$: square root of immersion time of "i"th data, $\overline{\sqrt{t}}$: average value of the square root of immersion time, L_i: penetration depth of the "i"th data, $\bar{L}$: average value of the penetration depth

The intercept of the approximate straight line is given as the constant B by the equation:

$$B = \bar{L} - A.\overline{\sqrt{t}} \quad (2)$$

Where B: constant, A: moisture penetration rate coefficient (mm/$\sqrt{hr}$), $\overline{\sqrt{t}}$: average value of the square root of immersion time, $\bar{L}$: average value of the penetration depth.

2.2 Surface Water Absorption Test (SWAT)

SWAT (shown in Fig. 1) is a non-destructive device that evaluates the quality of concrete at the cover zone under natural dominant water suction. SWAT has proven to be effective in detecting the influence of curing conditions and effects of microcracks, etc. in covercrete quality within 10-20 mm, which is the most affected by concreting works [3]–[6]. The rate of surface water absorption at 10 minutes (in which the time for pouring water is 10 seconds) measured by SWAT is termed p_{600} (in ml/m^2/s) and used as the criteria for quality grading as shown in Table 1.

Table 1 Grading of covercrete quality by SWAT

Water absorption rate at 10 minutes (600 seconds)	Quality		
	Good	Ordinary	Poor
p_{600} (ml/m^2/s)	<0.25	0.25 - 0.50	> 0.50

2.4 Coefficient of Water Absorption

Sorptivity is often determined from the gradient of the straight line obtained by plotting the cumulative water absorption per unit area against the square root of time[1]. It is often observed that the straight lines hardly pass through the origin, either with a negative intercept or with a positive intercept. Reasons for negative intercepts have been attributed to the dense surface layer and a slight delay in the start of timing, while for the positive intercept, a slightly early start of timing [1], [7].

The approach to the coefficient of water absorption by SWAT is the same with sorptivity, which is the slope from a linear regression obtained by plotting the cumulative water absorption per unit area against the square root of time. Modifications are applied to linear regression lines when intercepts at the origin are seen, as noted [1] that one-dimensional water absorption data usually produce an intercept at t = 0. Thus, the general equation defining one-dimensional water absorption is more correctly written as:

$$i = St^{1/2} + C \quad (3)$$

where i: cumulative absorbed volume of water per unit area of supply surface, S: sorptivity, t: time and C accounts for the negative or positive intercept.

3. EXPERIMENTAL PROGRAMME

3.1 Materials

Concrete specimens were prepared with ordinary Portland cement (OPC), ground granulated blast furnace slag cement (JIS type B slag cement) and JIS type II fly ash (FA) as 20% by weight of OPC replacing fine aggregate. Table 2 shows the concrete mix proportion and strength development. For each of the concrete mix designs, 15 cylindrical specimens (ϕ100 mm × 200 mm) were prepared among which 9 specimens were used for JSCE-G 582 and 6 specimens were used for compressive strength tests. 3 prismatic specimens (100 mm × 100 mm × 75 mm) were prepared for SWAT.

The concrete specimens were named as OPC_40 for OPC concrete 40% W/C, as OPC_50 for OPC concrete 50% W/C, as OPC-60 for OPC concrete 60% W/C, as BB_50 for BB cement concrete 50% W/C and as FA_50 for OPC plus FA concrete 41.6% W/B.

After casting, the specimens were sealed and kept in a controlled environment with temperature of 20°C and relative humidity of 60% for 28 days before demolding. Thereafter, the specimens were further left in the same controlled environment at the same temperature and humidity until 60 days after casting before test preparations and actual tests were conducted.

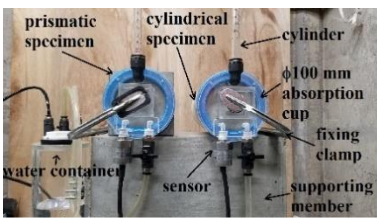

Fig. 1 Surface Water Absorption Test setup

Table 2 Concrete mix proportion and strength

W/C (%)	W/B (%)	s/a (%)	Mix composition (kg/m³)						Admixtures type and dosage(%)		Air cont-ent (%)	Compressive Strength (MPa)	
			Wat-er	OPC	BB	FA	Fine aggre-gate	Coarse aggregate (20mm max.)	Ad	AE		28 days	90 days
40	-	45.0	160	400	-	-	796	973	1.0	0.0015	5.6	41.9	49.1
50	-	47.0	160	320	-	-	865	975	1.0	0.0015	4.9	39.2	44.9
60	-	48.5	160	267	-	-	913	970	0.8	0.0015	4.3	27.6	33.9
50	-	46.7	160	-	320	-	854	975	0.8	0.0015	3.5	30.6	44.1
50	41.6	47.7	154	308	-	62	827	975	1.0	0.0045	3.8	40.2	45.7

Ad: Water reducing admixture, AE: Air entraining agent, dosage: percentage of admixture to binder, weight-to-weight ratio

3.2 Sample Preparations and Test Methods

(1) JSCE-G 582

For each mix design, 9 cylindrical specimens were prepared for JSCE-G 582 test for water penetration rate coefficients. The steps for sample preparations were in accordance with JSCE-G 582 2018 test method. To reduce the time for the preparation of the specimens, the drying time adopted in this study was 28 days drying at a temperature of 40 ± 2ºC and relative humidity of 30 ± 5%. Aluminum tape and epoxy resin were used for sealing the lateral sides and the surface that was not exposed by cutting.

The moisture penetration tests were also conducted in accordance with JSCE-G 582 2018 standard. The spacers used were point ended (Fig. 2) to ensure that they do not occupy up to 10% of the surface area of the specimen. For each specimen, 4 spacers were placed as illustrated in Fig. 3. The measurements were conducted at 5 hours, 24 hours and 48 hours respectively. For each measurement time, 3 specimens were measured for each of the concrete mix designs. The immersion was done in a controlled room of 20 ± 2ºC temperature and relative humidity of 60 ± 5%

The steps for measurements were as follows:
The specimen was split into two halves with a compressive strength testing machine. The water penetration depths were taken at five locations, L1-L5, from one half of the split specimen with a vernier caliper. The recorded measurements close to the edges (sealed sides) of the specimen were taken at a distance, 20 mm from the edge of the specimen. The water penetration depths (as shown in Fig. 4) were determined by spraying a colour-differentiating water dictator, which corresponds to the NDIS 3423 method.

(2) Surface moisture content

The surface moisture content of concrete was measured with kett HI-100 moisture tester. The Kett HI-100 surface moisture meter (which is based on the measuring principles of electrical resistivity) results are displaced in percentage (0-6%) or count values (40-990 counts). The count values have been shown to have an inverse linear relationship with electrical resistance. The advantage of this surface moisture meter over others is the ability to measure moisture content up to the depth of 5mm from the surface, which was confirmed by Komatsu et al, where a kett HI-100 revealed a higher correlation with the electric resistivity at the depth of 5 mm from the surface[5].

(3) Surface Water Absorption Test.

Before cutting and removing the 25 mm thickness from the face of the form-finished-surface of the cylindrical specimens, SWAT was conducted after 60 days of casting. The surface moisture contents were measured by kett HI-100 and recorded prior to SWAT. The same measurements were taken at the exposed surface after cutting out the 25 mm. The SWAT measurements on the cylindrical specimens were not utilized in evaluating the correlations between the two test methods. They were conducted to elucidate the influence of surface moisture content on SWAT.

The SWAT conducted on the prismatic specimens were utilized to evaluate the correlation between the two test methods. The prismatic concrete specimens were first exposed to sun drying to reduce the surface moisture content below the threshold for appropriate measurement of SWAT. The threshold value of HI-100 count value of 210 has been previously established by the authors which show sufficient dryness of surface covercrete ensuring accurate covercrete quality evaluation by SWAT [8].

SWAT measurements for this study were conducted so that water was absorbed in a horizontal direction as shown in Fig. 1.

(4) Compressive strength test

The strength development for the concrete specimens was investigated by compressive strength tests at 28 days and 90 days respectively. Results were averaged values from three ϕ100 mm x 200 mm cylindrical specimens.

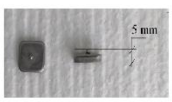

Fig. 2 Spacer

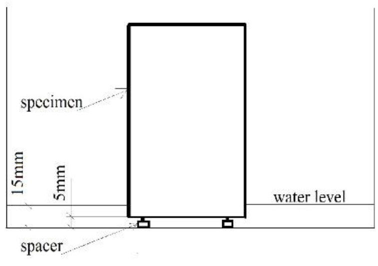

Fig. 3 Illustration of the placement of the spacers

4. RESULTS AND DISCUSSIONS

4.1 Water Penetration Rate Coefficient- A

Fig. 3 is an example of the waterfront observed by spraying the colour-differentiating water dictator for the measurement of the depths of moisture penetration.

Fig. 4 Water penetration depth

Table 3 shows the respective average penetration depths at 5 hours, 24 hours and 48 hours for the concrete specimens, the water penetration rate coefficient-A and the constant- B, obtained from JSCE-G 582 test. Just as expected, the penetration depth increased with immersion time and with the increase in W/C for OPC concretes. It can be inferred that the performances of BB_50 and FA_50 in resistance to moisture penetration were almost the same throughout the measurement. Table 3 revealed that the progress of penetration depth of BB concrete between 24 hours and 48 hours was very small compared to those of other concretes. This could be attributed to the discontinuity of pore connections of inside concrete of BB concrete resulting from the continuous hydration. This is evident in its time-dependent strength development shown in Table 2.

4.2 Coefficient of Water Penetration

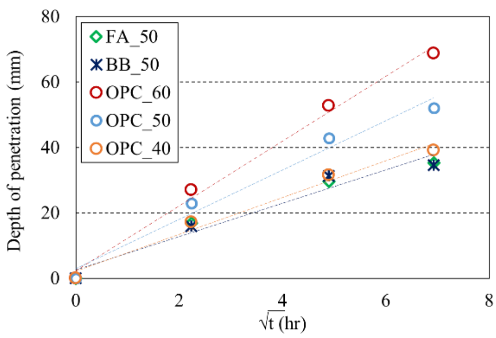

Fig. 5 Linear regression of penetration depth over square root of immersion time

From the linear regression of the plot of penetration depth (mm) over the square root of immersion time (in hours) shown in Fig. 5, the coefficient of water penetration was deduced and its relationship with the moisture penetration rate coefficient-A by JSCE-G 582 2018 as explained in equation (1) is shown in Fig. 6. A good correlation exists between the two indices, proving that the slope from the regression line is a good index.

4.3 Coefficient of Surface Water Absorption- CSWA

Fig. 7 shows the SWAT result (p_{600}) against the surface moisture content for the cylindrical specimens measured at 60 days. The moisture content estimated from the count values obtained from HI-100 moisture meter was much higher than the threshold value proposed by the authors even after 60 days of casting in this research. Threshold value is the maximum moisture content (210 count value of HI-100 moisture meter) beyond which the moisture content of concrete adversely affects the appropriate quality evaluation of covercrete. SWAT was conducted for these relatively wet concretes, whose results did not represent the actual evaluation of the covercrete quality of the concrete[8].

On the other hand, in Fig.8 (from prismatic specimens), SWAT result (p_{600}) shows much higher values than in Fig.7 due to lower HI-100 count values. The authors think that the results of SWAT in Fig. 8 with HI-100 count values lower than the threshold value of 210 exhibits the actual covercrete quality. Another clear indication of the accuracy of the evaluation is the visible effect of W/C in OPC concretes.

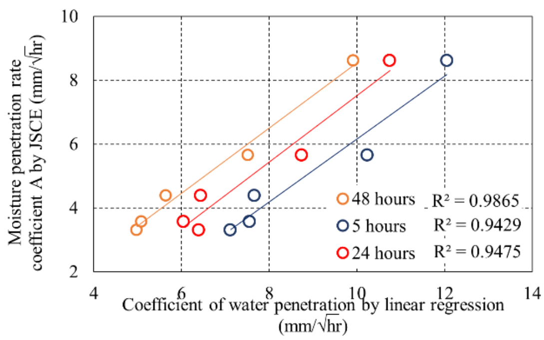

Fig. 6 Moisture penetration rate, A versus coefficient of water penetration

Table 3 The average moisture penetration depth and the moisture penetration rate coefficients of concrete

Type of concrete	Average Depth of Moisture Penetration (mm)						A: Moisture Penetration Rate Coefficient (mm/$\sqrt{hr}$)	B: Constant
	5 hours		24 hours		48 hours			
	Measured	L=A.√t+B	Measured	L=A.√t+B	Measured	L=A.√t+B		
OPC-40	20.2	21.1	34.7	33.0	42.2	41.8	4.4	11.4
OPC-50	27.2	28.8	47.1	43.9	56.1	55.1	5.6	16.5
OPC-60	30.2	31.4	55.8	54.6	72.0	71.8	8.6	12.5
BB-50	19.4	22.8	34.7	31.7	38.2	38.3	3.3	15.5
FA-50	20.7	22.2	33.5	31.9	39.1	39.1	3.6	14.3

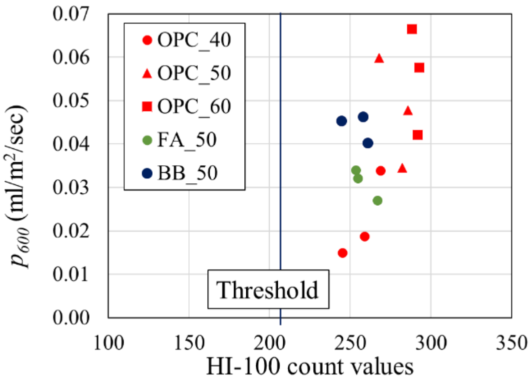

Fig. 7 p_{600} versus HI-100 count values of the cylindrical specimens after 60 days of casting

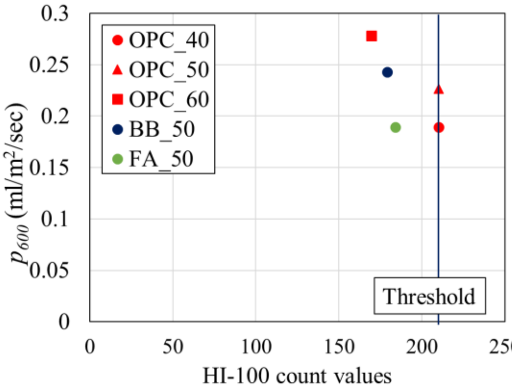

Fig. 8 p_{600} versus HI-100 count values of the prismatic specimens

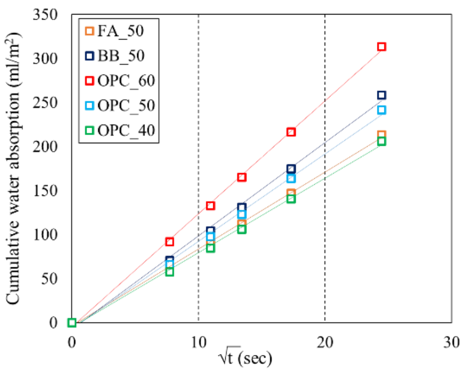

Fig. 9 Linear regression of cumulative water absorption by SWAT

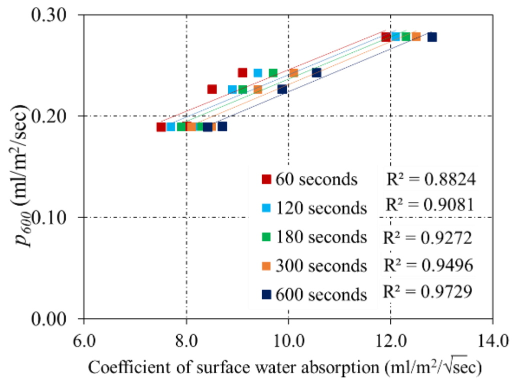

Fig. 10 Relationship between p600 and coefficient of surface water absorption

The coefficients of surface water absorption by SWAT (CSWA) were deduced from the linear regression shown in Fig. 9. CSWA was obtained by dividing the cumulative water absorption (in ml/m²) at 600 seconds (after the starting of SWAT measurement) by the square root of the measurement time (in seconds). The intercept C explained in equation 3 is taken as zero. Fig. 10 shows the relationship between p_{600} and CSWA at different measurement timings. It can be seen that a good correlation exists between the two indices. A new index of SWAT, CSWA can effectively be applied in the reduction of SWAT measurement time for the evaluation of covercrete quality of existing RC structures.

4.4 Relationship between the Two Test Methods.

In the case of SWAT, concrete quality is evaluated by measuring the resistance against water absorption in 10 minutes. In this research, SWAT was conducted before removing 25mm thickness from the bottom surface of cylindrical specimens, therefore coarse aggregate was not exposed. On the other hand, in JSCE-G 582 test, 25 mm thickness of concrete was removed from the bottom surface before conditioning and subsequent measurement thereby included the direct influence of exposed aggregate on water absorption. Furthermore, JSCE-G 582 requires long-term drying of specimens to achieve almost steady weight and also requires destructive tests until 48 hours after starting water penetration. Due to the destructive nature of JSCE-G test result, it can not be applied for the evaluation of covercrete quality of actual structures.

Fig. 11 shows the relationship between the coefficient of surface water absorption- CSWA from SWAT results and the coefficient of water penetration from JSCE-G 582 test results. From this figure, it is shown that the moisture coefficient of water penetration by the JSCE-G 582 test and CSWA are correlated with a correlation coefficient of 0.78. A high p-value of 0.12 can be seen from the result. Similarly, Fig. 12 is showing, the cumulative water absorption from SWAT against the depth of penetration from the JSCE-G 582 test, where a correlation exists with a correlation coefficient of 0.80. A similar p-value of 0.11 was revealed.

SWAT and JSCE-G 582 results have good correlation, however, the number of data is limited at present, and further investigation is necessary. Especially, BB concrete is showing much higher resistance against water absorption in JSCE method than in SWAT, which might be related to the denseness of inner concrete where SWAT is not sensitive.

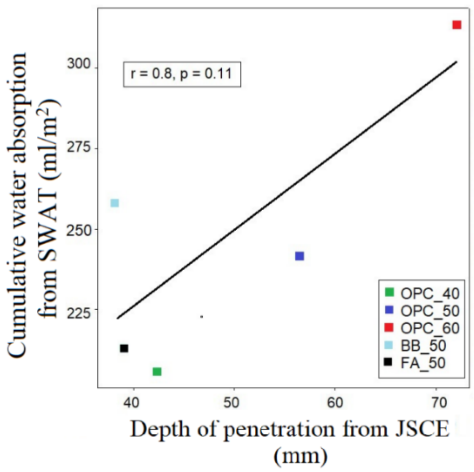

Fig. 11 Correlations between CSWA and coefficient of water penetration by JSCE

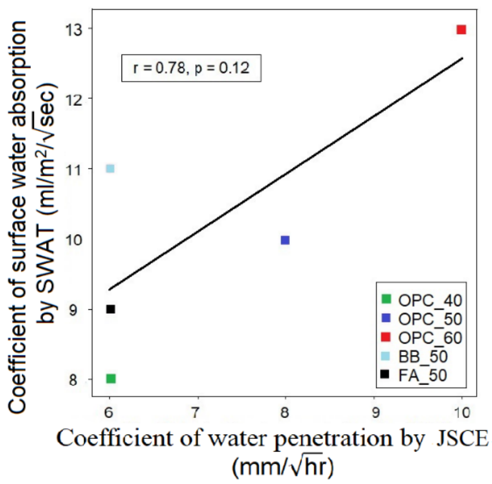

Fig. 12 Correlations between cumulative water absorption from SWAT and depth of penetration from JSCE-G 582

5. CONCLUSIONS

This study investigated the correlations between SWAT and the JSCE-G 582 test standard, and proposed a new SWAT quality grading index, by utilizing concrete mixtures with varying cement types (OPC, BB and FA) and W/B content (40%, 41.6%, 50% and 60%). The following conclusions can be drawn:

(1) A correlation exists between the coefficient of surface water absorption-CSWA by SWAT and the coefficient of water penetration by JSCE-G 582 test with a correlation coefficient of 0.78. Similarly, a correlation exists between the cumulative water absorption from SWAT and the depth of penetration from the JSCE-G 582 with a correlation coefficient of 0.80. This implies that any of the two indices from SWAT could effectively be applied to evaluate the resistance of concrete to moisture penetration without going through the destructive and rigorous process of calculating the moisture penetration rate. However, the number of data is quite limited, so further investigation is necessary.

(2) The coefficient of water penetration from JSCE-G 582 which was obtained from the slope by linear regression has a good linear relationship with the moisture penetration rate coefficient obtained by JSCE-G 582 calculation formula, A.

(3) Compared to other concretes, BB concrete showed much higher resistance against water absorption in JSCE method than in SWAT, which might be related to the denseness of inner concrete where SWAT is not sensitive

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