- Technical Paper -

EFFECTS OF INNER MOISTURE OF COVERCRETE ON SURFACE WATER ABSORPTION TEST AND AIR PERMEABILITY TEST

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ABSTRACT

Effects of moisture content in many kinds of moisture profiles of concrete on Surface Water Absorption Test (SWAT) and on double chamber air permeability test were investigated. Moisture content was measured by two surface moisture meters, and electric resistance was measured by embedded sensors at several depths. It was found in some cases that water absorption resistance p_{600} and air permeability coefficient kT showed smaller values though the surface moisture content was small enough, which might have been due to inner high moisture content.

Keywords: SWAT, air permeability, moisture content, relative humidity (R.H.).

1. INTRODUCTION

The durability of concrete structures is always one of the biggest concerns in the worldwide construction, in which surface permeability causes the structural degradation of concrete. Surface absorption is influenced by some factors. Moisture content is one of them [1]. The moisture content change in covercrete caused by wetting and drying processes has a considerable effect on water absorption and air permeability.

Many methods for non-destructive measurement of covercrete surface absorption have been proposed recently. Surface Water Absorption Test (SWAT) device developed by the authors [2], [3] is used in this research. A double chamber air permeability test proposed by Torrent, et al. is also used in this research [5]. It is known that moisture content in covercrete affects surface water absorption results by SWAT and air permeability result by double chamber air permeability method [6]. Therefore, the moisture content of covercrete has to be confirmed before conducting SWAT and air permeability tests. It has been found out that CMEX-II and HI-520-2 can be used to evaluate appropriate moisture content of covercrete before conducting SWAT and air permeability test [6]. However, the patterns of moisture distribution inside concrete in the past research [6] are limited. Studies related to the influences of moisture content on surface permeability considering real outside environments are so much limited.

The objective of this present study is to deeply investigate the effects of inner moisture content of covercrete on water absorption and air permeability with various kinds of moisture distribution.

In this paper, to obtain many kinds of moisture profiles in covercrete, specimens are subjected to many kinds of ambient R.H. conditions before conducting SWAT and double chamber air permeability test. Electrical sensors are embedded at several depths in covercrete in some of the specimens, and electric resistance related to moisture content is measured during wetting and drying.

Before conducting SWAT and air permeability measurement, moisture content of covercrete is measured by two kinds of moisture meters. The effects of inner moisture content of covercrete on SWAT and air permeability test will be clarified, and the effectiveness of those moisture meters to evaluate whether covercrete is appropriately dry or not will be investigated.

2. MEASURING DEVICES

2.1 SWAT

SWAT is a fully non-destructive test developed by Hayashi and HOSODA [2], [3]. It consists of a water cup with a graduated tube, as shown in Fig.1. From the measured absorption data, p_{600}, defined as the rate of water absorption at 10 minutes (600 seconds) after the start of measurement, is calculated in (ml/m^2/s). The authors have proposed two threshold values for evaluating covercrete quality as shown [2], [3].The amount of absorbed water in one to 10 minutes can also be an index to evaluate the resistance against water absorption [7].

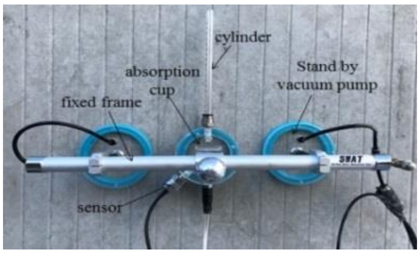

Fig.1 SWAT device

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2.2 Double chamber air permeability tester

Double chamber air permeability tester is used to measure air permeability in this research, and *kT*, coefficient of air permeability is obtained. The criterion for evaluating covercrete quality has been proposed [4].

It has also been proposed that air permeability results can be adopted when the surface moisture content measured by CMEX-II device is 5.5% or less [5].

2.3 Moisture meters

Two kinds of moisture meters, namely CMEX-II and HI-520-2 are used to measure the moisture content of concrete at the surface of the specimens.

CMEX-II detects and evaluates the moisture conditions in concrete by measuring the electrical impedance. A low frequency electronic signal is transmitted into the material under test device. The strength of this signal varies in proportion to the amount of moisture present in the material. The CMEX-II determines the strength of the current and converts this to a moisture content value for concrete

HI-520-2 is a handy high-frequency capacitive moisture tester with an integrated main unit and sensor section. When concrete contains water, the conductivity will increase. This makes it possible to determine the moisture content by determining the relationship between moisuture content and conductivity. The value obtained in this way is displayed as the measured moisture content.

3. EXPERIMENTAL PROCEDURES

3.1 Materials and mix proportion

Ordinary Portland cement was used to make 18 rectangular specimens in total. The only one mix proportion shown in Table 1 was used. The maximum coarse aggregate size was 20mm. Air content of concrete was set as 4±0.5%. The structural dimensions of the specimen are shown in Fig.2.

3.2 Sensors to measure electric resistance

Electric sensors are used to evaluate electric resistance related to moisture content of concrete in depth direction from the surface. The change in electric resistance (count value) between the coupled embedded electrode bars is measured by HI-800. Each sensor was made with two steel bars of SUS 304, M4. The distance between the two bars is 10mm. For each specimen, 5 sensors in total are arranged at the depth of 5mm, 10mm, 20mm, 30mm, and 50mm as shown in Fig.2(c). HI-800 will give us "count values" as output, however, the relationship between the count values and the electric resistances have been reported in a past research [8].

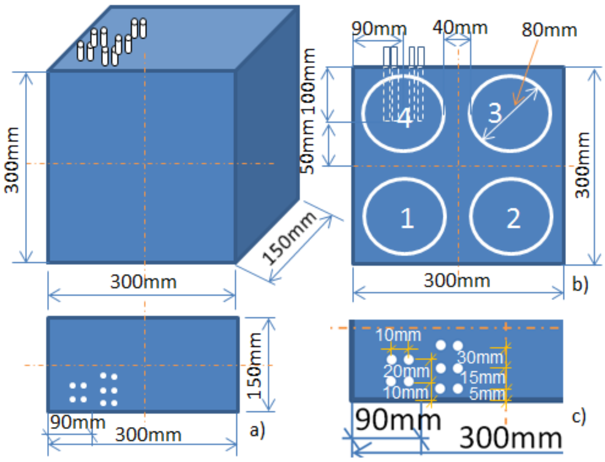

Fig.2 a) Shape of specimen, b) Measurement locations, c) Arrangement of sensors

3.3 Curing conditions

Curing conditions of specimens in this research are explained here. All the specimens were placed in the curing room. In the curing room, the temperature was set at (20±1)^{o}C and the R.H. was set at (60±2)%. After the placing, 3 kinds of initial curing conditions explained below were applied.

(1) Formwork was removed at one day after placing. After that, the specimens were exposed in the curing room mentioned above.

(2) Formwork was removed at 7 days after placing. After that, the specimens were exposed in the curing room.

(3) Formwork was removed at one day after placing. After that, the specimens were cured in water of (20±1)^{o}C for 6 days until the age of concrete became 7 days. Then, the specimens were exposed in the curing room.

Six numbers of same specimens were made for these 3 kinds of initial curing conditions explained above. In total, 18 specimens were made.

3.4 Environmental conditions for producing different moisture profiles

The 18 specimens were divided into two series. In Series 1, after finishing 3 kinds of initial curing, 9 specimens were kept in the curing room for around 60 days. After that, 9 specimens were divided into 3 different R.H. environments, namely 60±2%, 80±2% and 99.9% for 1 or 2 days. The temperature in those 3 rooms was (20±1)^{o}C. Finally, 9 different moisture profiles could be obtained. The experimental procedures are summarized in Table 2. Actually, the results of this Series 1 for W/C 50% concrete were included in the past research [6].

Table 1 Mix proportion of concretes

Max. aggregate (mm)	Slump (cm)	Air (%)	W/C (%)	s/a (%)	Unit content(kg/m^3)					
					W	C	Fine aggregate	Coarse aggregate	Admixture	
									[1]Ad	[2]AE
20	12	4.5	50	47	160	320	841	685	3.2	0.64
[1]Ad: Water reducing admixture, [2]AE: Air entraining agent										

Table 2 The experimental procedures of Series 1

Initial curing conditions after placing	Duration to keep in the curing room	Number of specimens in high R.H.			Measurement
		60±2%	80±2%	99.9%	
3 specimens-sealed 1 day	60 days in curing room	1	1	1	Measuring SWAT and air permeability after 1 or 2 days
3 specimens-sealed 7 day		1	1	1	
3specimens-sealed 1 day, 6 days in water		1	1	1	

Table 3 The experimental procedures of Series 2

Initial curing conditions after placing	Duration to keep in the curing room	High R.H. condition	Number of specimens in high R.H.			Measurement
			60±2%	80±2%	99.9%	
3 specimens-sealed 1 day	90 days in curing room	7 days in 99.9% R.H. room	1	1	1	Measuring SWAT and air permeability after 3,7 and 14 days
3 specimens-sealed 7 day			1	1	1	
3specimens-sealed 1 day, 6 days in water			1	1	1	

In Series 2, after finishing 3 kinds of initial curing, 9 specimens were kept in the curing room for around 90 days. After that, all the 9 specimens were moved into high R.H environmental conditions (temperature (20±1)^{o}C, R.H 99.9%) for seven days. After that, they were moved back to the curing room. 3 kinds of waiting time before conducting SWAT and air permeability test were provided, that is 3, 7, and 14 days. Finally, 9 different moisture profiles could be obtained. The experimental procedures are summarized in Table 3.

3.5 Water absorption and air permeability test

SWAT and air permeability test were conducted for all the specimens after achieving many kinds of moisture profiles. SWAT and air permeability measurements were conducted basically at 4 points on both sides of the specimens as shown in Fig.2b.

Moisture content was measured at the surface of each measuring point before conducting SWAT and air permeability test. Moisture content was measured by two moisture testers, CMEX-II and HI-520-2.

After measuring the moisture content, air permeability test was conducted. SWAT was conducted at the same measurement points at least 20 minutes after air permeability test. It was reported that 20 minutes were sufficient for inner pressure of concrete to come back to the original state for conducting air permeability test again at the same location [9].

4. RESULTS AND DISCUSSIONS

4.1 Case 1: (Initial curing : Sealed for 1 day)

In Fig.3(a), (d), Series 1 results (blue color) show that p_{600} seems apparently smaller when the moisture content measured by CMEX-II is higher than around 6.0% and also when the moisture content measured by HI-520-2 is higher than around 5.0%. In the same figures, Series 2 results (red color) seem to show relatively small p_{600} compared to Series 1 results for the same moisture content.

Fig.3(b), (e) show the results of p_{600} measured at the locations where electric sensors are embedded. These results are included also in Fig.3(a), (d).

In, Fig.3(b), (e), p_{600} is apparently small in two points though the moisture content is not so high. The moisture contents measured by CMEX-II in those two points are smaller than 5.5%. The authors guess that the reason for this is high moisture content of concrete at some depth which cannot be detected by the two moisture meters used in this research.

Fig.3(g) shows the change of count values measured by HI-800 at the depth of 5mm from the surface. The count values increased due to wetting in high R.H. rooms, and after that decreased due to drying in the curing room. The measurement of SWAT was conducted in each condition with the last count value recorded in Fig.3(g). At the timing of SWAT measurement, two specimens in Series 2, 99.9%-3D and 99.9%-7D still showed higher count values meaning higher moisture content at that depth. CMEX-II and HI-520-2 could not detect this high moisture content at the depth of 5mm.

In Fig.3(c), (f), air permeability results also exhibit that some results of Series 2 are showing relatively smaller kT for same moisture contents measured by CMEX-II and HI-520-2. This may also be caused by high moisture content inside concrete which could not be detected by these two moisture meters.

Fig.3(h) shows the relationship between count values and p_{600} results. It is apparent that the specimens with count values lower than 300 showed larger p_{600}.

4.2 Case 2: (Initial curing: Sealed for 7 days)

Fig.4 shows the measurement results for the specimens with seven days sealing condition. In general, same kind of trends observed in Fig.3 were seen in Fig.4. However, due to better initial curing condition, variations in both horizontal and vertical axes in figures (a) to (f) were smaller. In Fig.4(a), Series 2 results are showing smaller p_{600} for the same moisture content, though the moisture content measured by CMEX-II was smaller than 5.5%. In the same way, in Fig.4(c), Series 2 results are showing smaller kT for the same moisture content, though the moisture content measured by CMEX-II was smaller than 5.5%. These must have been caused by high moisture content inside which could not be detected by CMEX-II.

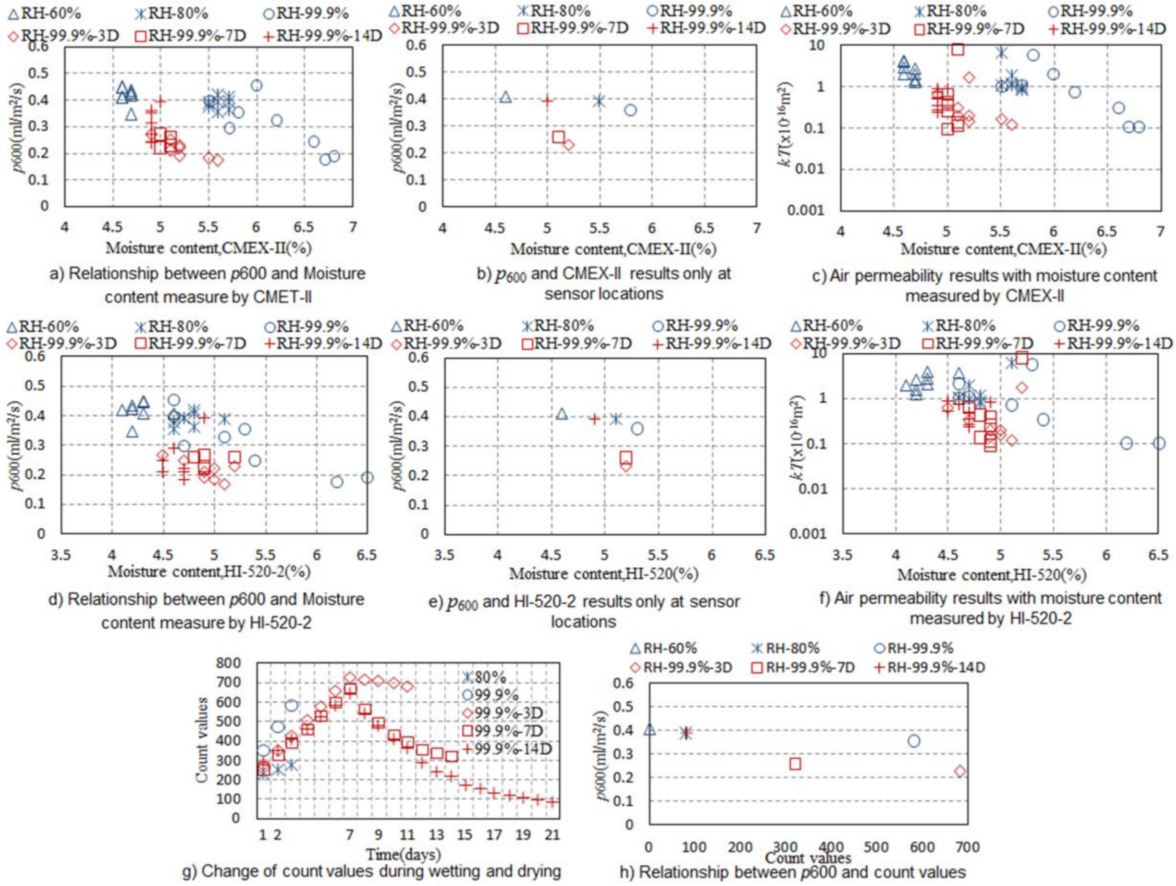

Fig.3 Measurement results for the specimens with 1 day sealing curing condition

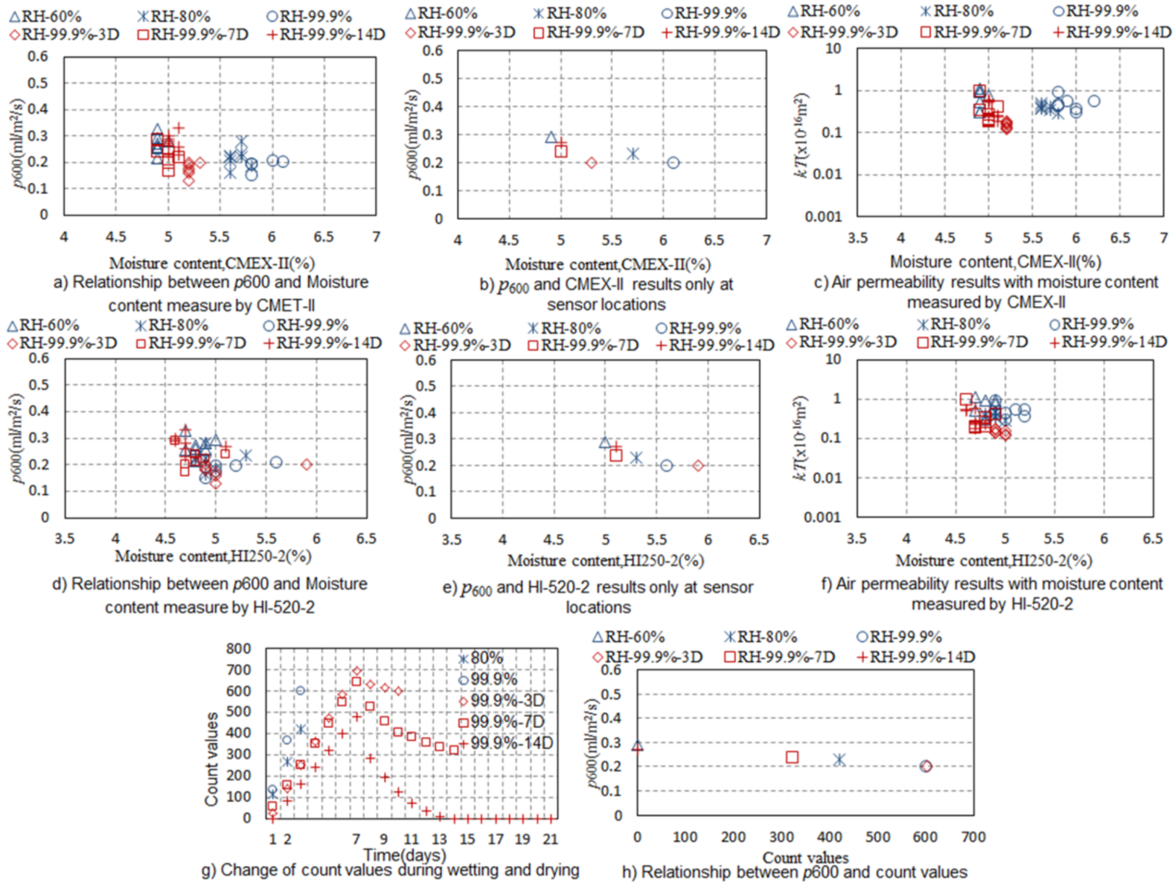

Fig.4 Measurement results for the specimens with 7 day sealing curing condition

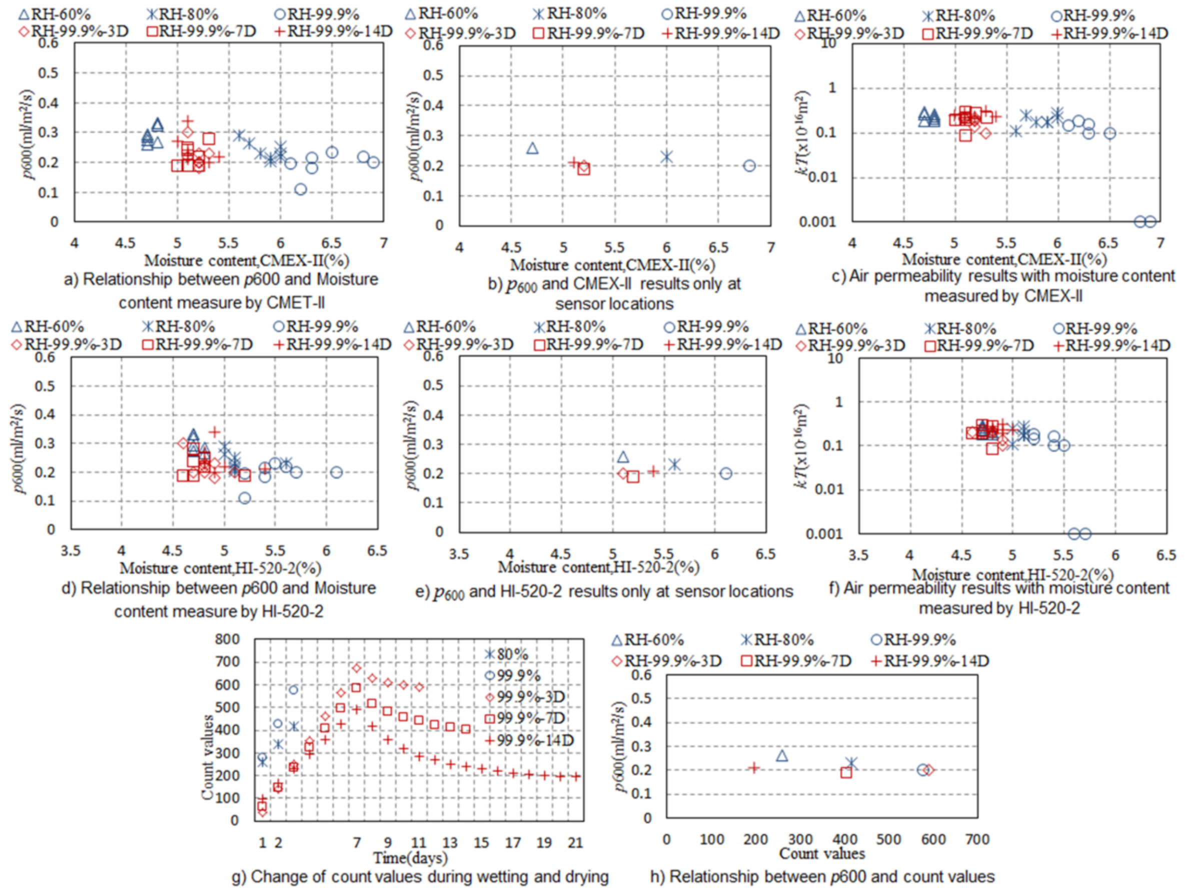

Fig.5 Measurement results for the specimens with 1 day sealing and 6 days in water

In Fig.4(d) and (f), same kind of effects of inner high moisture content can be seen for Series 2 results.

When we look at Fig. 4(b) and (e) whose reults were obtained at embedded sensor locations, it seems that 2 data among 6 are showing relatively larger p_{600}. Those 2 are "R.H.-60%" in Series 1 and "R.H.-99.9%-14D" in Series 2. Looking at Fig.4(g), the count values of 4 specimens other than those 2 explained above were higher, which meant higher moisture content at 5mm depth.

Fig.4(h) shows the relationship between count values and p_{600}. The variation in p_{600} was not so large, however the specimens with count values lower than 300 showed relatively larger p_{600}.

4.3 Case 3: (Initial curing: Sealed for 1 day and 6 days in water)

Fig.5 shows the measurement results for specimens with 1 day sealing and 6 days in water condition. Same kind of tendency can be observed as in Fig.3 and Fig.4, however, in Fig.5 the difference between Series 1 and Series 2 seemed more ambiguous than in other 2 cases. This is because the moisture contents at 5mm depth in all the 6 specimens were relatively high (Fig.5 (h)) due to the best initial curing condition. In Fig.5 (a), (d), some results of Series 2 are showing relatively small p_{600} for the same moisture content.

In Fig.5(c), (f), air permeability results were not affected by moisture content when the moisture content measured by two moisture meters were smaller than some values (CMEX-II:6.5%, HI-520-2:5.5%).

Fig.5(h) shows the relationship between count values and p_{600} results. All the specimens showed relatively higher count values compared to Fig.3(h) and Fig.4(h), and the effects of count values on p_{600} were not clearly seen in this figure.

4.4 Effects of moisture content at 5mm and 10mm depth.

In this research, in from 4.1 to 4.3, the count values at 5mm were used for investigating the effect of inner moisture content. We are still not sure whether the count values at 5mm or at deeper locations are meaningful.

In the past research [10], count values measured at 5mm were effective to evaluate the extent of drying for RC slab specimens subjected to long term wetting. Komatsu et al. pointed out that HI-100, another surface moisture meter was effective to detect the dryness at 5mm depth.

In Fig.6, count values at 5mm and 10mm during wetting and drying for Case 1 are shown. Count values at 10mm were relatively higher than those at 5mm. Count values at 10mm were also affected by wetting and drying, however they did not return to the original level even after drying for 14 days.

Fig.7 shows the relationship between count values and p_{600}. It is found that the count values at 5mm are much more sensitive in the wetting and drying condition in this research, and the specimens with count values lower than around 200 showed apparently larger p_{600}.

The authors will continue to investigate the effect of moisture content and appropriate usage of surface moisture meters.

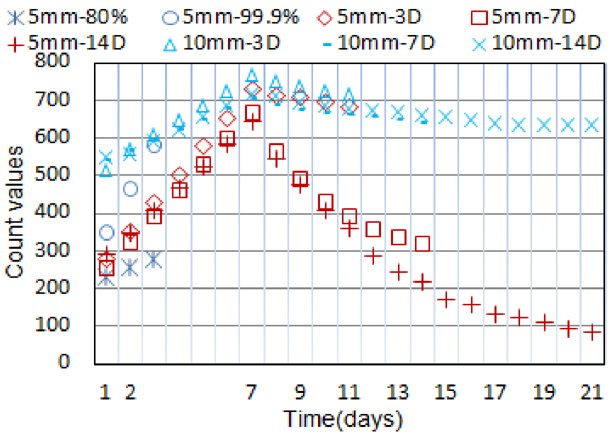

Fig.6 Change of count values during wetting and drying

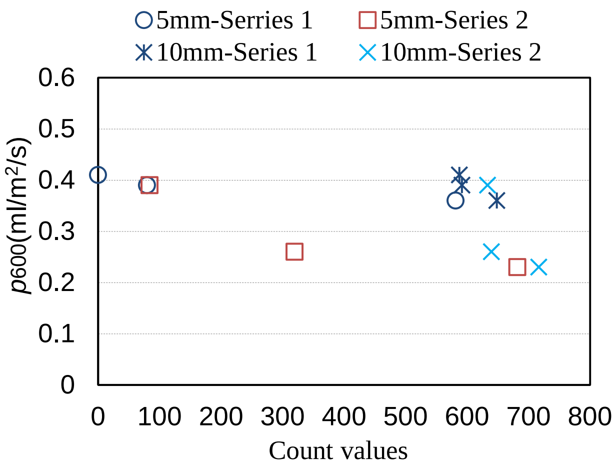

Fig.7 Relationship between p_{600} and count values

5. CONCLUSIONS

In this research, effects of moisture content in many kinds of moisture profiles of concrete on Surface Water Absorption Test (SWAT) and on double chamber air permeability test were investigated. Moisture content was measured by two surface moisture meters (CMEX-II and HI-520-2), and electric resistance was measured by embedded sensors at several 5-30mm depths. The following conclusions were experimentally obtained.

(1) Specimens subjected to long wetting (Series 2) tended to show lower p_{600} and kT for the same moisture content measured by two surface moisture meters. The reason may be higher moisture content inside which could not be detected by those surface moisture meters.

(2) The effects of moisture content mentioned in conclusion (1) were clearly observed when initial curing condition of concrete was not good (Case 1: Sealed for 1 day). The effects became ambiguous when the initial curing condition was the best (Case 3: Selaed for 1 day and 6 days in water).

(3) Count values related to electric resistance of concrete at 5mm depth may be useful to evaluate whether covercrete is sufficiently dry or not for SWAT and air permeability measurements.

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