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REEVALUATION OF THE EFFECT OF COVERING SHEETS FOR REDUCING BUGHOLES ON TUNNEL LINING CONCRETE

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Most tunnel lining concretes have sidewall of negative angle, so bugholes on the concrete surface frequently appear. The bugholes are caused from entrapped air in concrete placing; the part of bugholes remains on concrete surface even after adequate vibrating for consolidation. In the previous investigation, the authors have studied on the generation mechanism of bugholes in a visible test and examined the reducing effects by covering sheet for concrete forms. According to the investigation, it was found that the water-permeable sheet causes color irregularity of concrete surface while the sheet is effective to decrease the bugholes. Hence, the present study also focuses on the effect of sheets reducing bugholes. The foci of this study are to develop an effective sheet for aesthetic of concrete surface and to reevaluate the effectiveness for reduction of bugholes. Fundamental test using a model form and various covering sheets was performed by referring to the previous investigation. The test confirms that the developed sheet adequately contributes on decrease of bugholes without the color irregularity of concrete. The observations may be useful for most concrete construction as well as tunnel lining concrete.

Keywords: Tunnel lining, Bughole, Covering sheet, Gas permeability, Water permeability, Breathable-waterproof material.

1 INTRODUCTION

It is well known that the durability of concrete structures is affected by surface quality. In addition, the surface quality is strongly related to aesthetic of concrete structures. Figure 1 demonstrates typical degradations for aesthetic; (a) concrete spalling, (b) water stains, (c) bugholes, and so on. This study focuses on improvement of surface quality of tunnel lining concrete. Yoshitake *et al.* (2012) reported the influencing factors for aesthetic of tunnel lining concrete. In particular, bugholes often occur on concrete surface of sidewall of tunnel lining even in an appropriate construction. However, it has been difficult to decrease bugholes effectively. The previous studies investigated the generation mechanism of bugholes using a visible testing form, and examined the reducing effects by covering sheet for concrete form (Maeda *et al.* 2014; Harada *et al.* 2015). The study reported that the color irregularity of concrete was observed while the water permeable sheet is an effective material to reduce bugholes (Harada *et al.* 2015). The foci of this experimental investigation are to confirm the reducing effect by covering sheets and to develop a suitable sheet for reduction of color irregularity as well as decrease of bugholes. Based on a laboratory test, the paper discussed and reevaluates the surface-quality improvement effect of the covering sheet.

(a) concrete spalling (b) water stains (c) bugholes

Figure 1. Typical degradations in tunnel lining concrete.

2 METHODOLOGY

2.1 Concrete

Table 1 gives a mixture proportion of concrete. The concrete mixture is referred to the mixture proportion used in the previous study (Harada *et al.* 2015). The specified compressive strength of concrete was 21 MPa, and slump value was 150 mm. Further information of the concrete were described in the previous study.

Table 1. Mixture proportion.

w/cm	Unit weight (kg/m^3)							
	Water	BBC[a]	Aggregate				Water reducing agent	AE agent
			Fine	40-20 mm	20-15 mm	15-5 mm		
0.59	165	280	726	455	342	342	0.42-2.94	0-0.021

a: blast furnace slag cement (type B) defined in JIS R 5211

2.2 Covering Sheets

As mentioned earlier, color irregularity was observed in concrete made with the water permeable sheet. It was found that the color gradation was caused from discharged water via the permeable sheet. The previous study confirmed that breathable-waterproof materials sheets can decrease bugholes while the function was not better than the performance of water permeable sheet. Hence, four kinds of breathable-waterproof materials sheet were additionally employed to decrease the color irregularity.

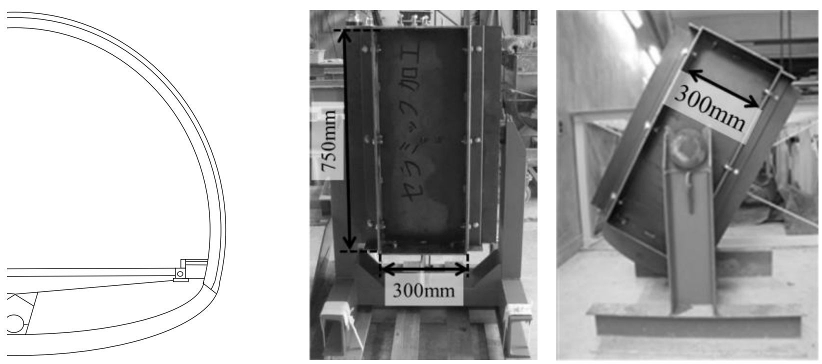
Table 2 summarizes test parameters. The tested sheets having variable Gurley number and water bearing pressure was prepared.

Table 2. Test parameters.

No.	Water bearing pressure (kPa)	Gurley number (sec/100cc)	Water-repellent	Remover
1	200	10	No	Use
2	200	10	No	N/A
3	100	12	Yes	Use
4	100	12	Yes	N/A
5	30	4	No	Use
6	7	1	No	Use

2.3 Test Specimens and Procedure

Concrete specimens, dimensions of 750 x 300 x 300 mm, were prepared to simulate sidewall of tunnel lining. Figure 2 shows a special concrete form as well as the previous investigations (Maeda *et al.* 2014; Harada *et al.* 2015). Concrete is cast into the form with an angle of 30 degree. All concrete specimens were consolidated by using a vibrator of 220-280 Hz at the central-section of the specimen for 60 seconds.



(a) schematic of lining concrete (b) front view (c) side view

Figure 2. Steel form simulated tunnel lining.

2.4 Evaluation Method for Bugholes

An image analysis directly using colored photographic image was used to detect bugholes in addition to the previous study (Harada *et al.* 2015). Figure 3 presents the image analysis system. In this system, RGB values in each pixel of the photographic image are compared to the reference number for each color; and a pixel is estimated as an element of photographic image of bughole when all RGB values of the pixel are lower than the reference criterion. It should be noted that bugholes of 0.7 mm or less, negligible size for aesthetic, were omitted in the evaluation.

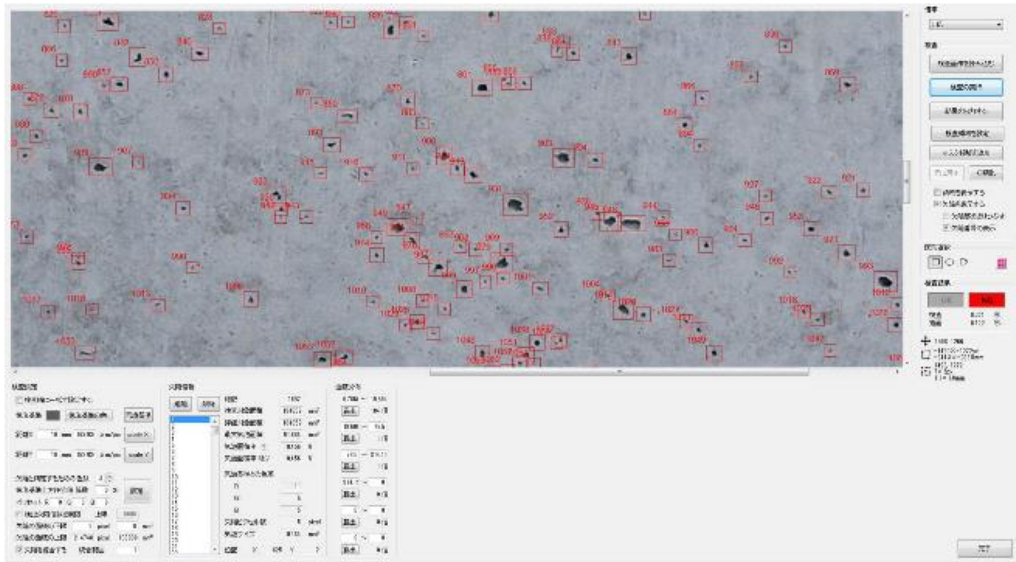


Figure 3. Image analysis using colored photographic image.

3 TEST RESULTS AND DISCUSSION

Figure 4 presents a relation between area-ratio of bugholes and Gurley number in this investigation. A regression line is also presented in the graph. The result shows that area-ratio of bug holes increases in accordance with Gurley number. The increasing ratio, that is the coefficient of the regression line, was almost 0.07 %/(sec./100cc). It is noteworthy that the area-ratio of bughole of concrete using the sheet without remover (unfilled-markers) were higher than the ratio of concrete using the sheet with remover (solid-markers). The observation may imply that the air/water drainage-effects of the sheet surface were promoted by the remover.

Figure 5 presents the area-ratio of bugholes of concrete made with the various sheets having different water bearing pressure. The test results of No.3 and 4 were significantly greater than other results because of water-repellent function in the sheet. Except for the test results of No.3 and 4, a regression line is obtained from the results. The increase of the ratio in the regression line was not remarkable compared with the result shown in Fig.4, while the area-ratio of bughole was also increased in accordance with the water bearing pressure.

Figure 6 demonstrates the concrete surface in the test of No.6. The result confirm that the covering sheet adequately contributes on decrease of bugholes without the color irregularity of concrete. Further investigation, such as actual applications, should be conducted to determine the most suitable covering sheet for improvement of aesthetics of tunnel lining concrete.

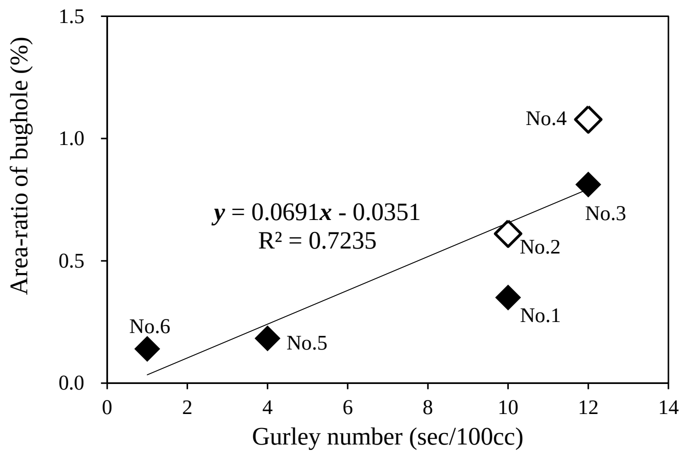


Figure 4. Relation between area-ratio of bugholes and Gurley number of covering sheet.

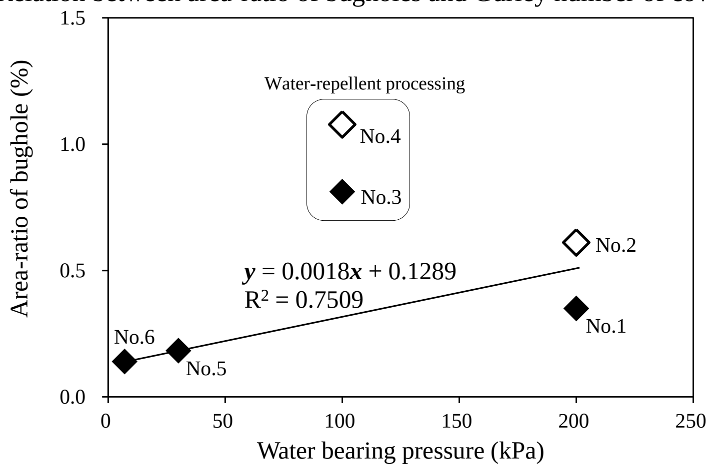


Figure 5. Relation between area-ratio of bugholes and water bearing pressure of covering sheet.

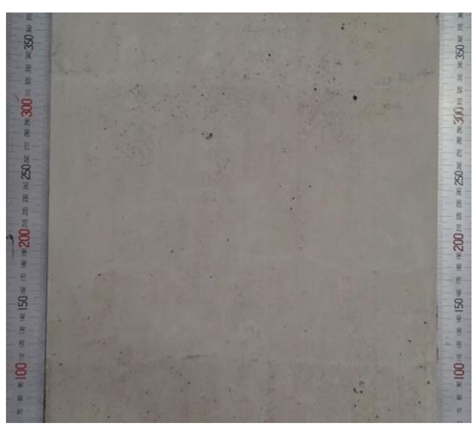


Figure 6. Concrete surface condition without color irregularity (No.6).

4 CONCLUSIONS

The foci of the study were to reevaluate the effect of breathable-waterproof materials sheet and to develop a suitable sheet for reduction of color irregularity as well as decrease of bugholes. The laboratory test confirmed the relation between bugholes and properties of the covering sheet. The conclusions of this fundamental investigation are as follows:

- The number of bugholes is almost proportional to the increase of Gurley number of the covering sheet.
- The area-ratio of bughole of concrete using the sheet without remover were higher than the ratio of concrete using the sheet with remover.
- The area-ratio of bughole was increased in accordance with the water bearing pressure of the covering sheet, however, the increase was not remarkable compared with the relation between bugholes and Gurley number.
- The laboratory test confirmed that the breathable-waterproof materials sheet contributes reduction of bugholes and color irregularity.

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