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REDUCING BUG-HOLES ON TUNNEL LINING CONCRETE BY USING COVERING SHEETS

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This study focused on bug-holes on sidewalls of tunnel lining concrete. The bug-holes of lining concrete may negatively affect aesthetics and durability of NATM (New Austrian Tunneling Method) tunnels. Most bug-holes appeared on concrete surface are generated from entrapped air during consolidating concrete. In particular, the sidewall of tunnel lining is constructed with negative angles, so bug-holes are often observed on the sidewall. Seven concrete specimens were prepared to simulate conventional tunnel lining. In the experimental investigation, breathable-waterproof material sheets and permeable sheets were used. The primary experimental parameters are (a) covering-sheet materials and (b) form surfaces such as ceramic-coated steel with grooves. The study examined bug-hole distributions in the concrete specimens using the various sheets. The bug-hole distributions were quantified by using an image analysis developed in this study. The test results show that quantity of bug-holes of concrete using the sheets is lower than the quantity of concrete without sheets. It was noteworthy that the bug-holes were hardly observed in the test using the form covered with the permeable sheets.

Keywords: Air bubble, Lining concrete, Concrete surface, Covering-sheets.

1 INTRODUCTION

Most experimental research on concrete bug-holes has been conducted to quantify the voids on concrete surface (Ozkul *et al*. 2012, Wilson *et al*. 2013). This study aims at reducing bug-holes on sidewalls of tunnel lining concrete. Bug-holes are imperfections that appear on a concrete surface after demolding. The bug-holes of lining concrete may negatively affect aesthetics and durability of NATM tunnel (Yoshitake *et al.* 2012). In particular, the sidewall of tunnel lining is constructed with negative angles (Figure 1), so bug-holes are often observed on the sidewall (Maeda *et al.*, 2014). The experimental investigation prepared the specimen simulated conventional tunnel lining, and examined bug-holes distributions of the lining concrete specimens. To reduce bug-holes of concrete, fundamental tests were performed by using form-covering sheets and various forms. The foci of the experimental investigation are to confirm the effect of covering sheet for reducing bug-holes on concrete surface and to examine the combined effect by the form surface covered with the sheet. The paper presents the experimental investigations based on a laboratory test. The findings in the fundamental experiments may contribute to the durability of tunnel lining in addition to the aesthetics.

2 METHODOLOGY

2.1 Materials

Concrete and sheets used in this study are described below:

2.1.1 *Concrete*

Table 1 gives mixture proportions of concrete. The mixture proportions were designed by referring to a conventional lining concrete having compressive strength of 21 MPa at the age of 28 days, and slump value of 15 cm. Table 2 summarizes materials for the concrete mixture.

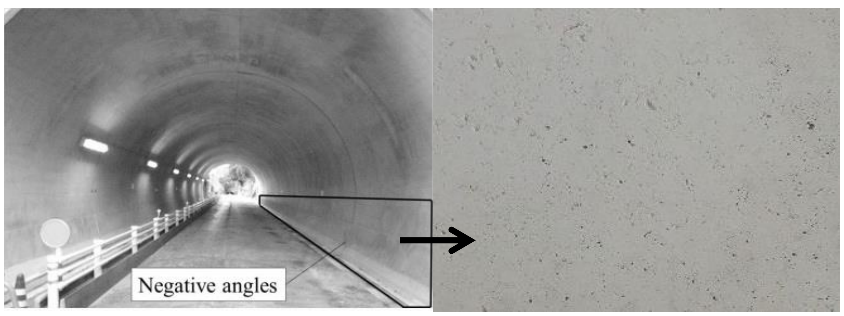


Figure 1. Sidewall of tunnel lining concrete.

Table 1. Concrete mixture proportion.

	w/cm	Unit of weight (kg/m^3)							
		W	C	S	G_1	G_2	G_3	WRA	AE
A	0.59	165	280	726	455	342	342	0.42~3.36	0~0.084
B	0.59	165	280	726	454	341	341	2.24	-

Table 2. Materials.

Materials	Symbol	Properties
Cement	C	Blast-furnace slag cement (B), density: 3.04g/cm^3
Fine aggregate	S	Sea sand, density: 2.60g/cm^3
Coarse aggregate	G_1	Crushed sandstone, Maximum size : 40mm density: A 2.72g/cm^3, B 2.70 g/cm^3
	G_2	Crushed sandstone, Maximum size : 20mm density: 2.73g/cm^3, B 2.72 g/cm^3
	G_3	Crushed sandstone, Maximum size: 15mm density: 2.70g/cm^3
Admixture	WRA	Water reducing agent
	AE	Air entraining agent

2.1.2 *Covering sheets*

Two kinds of covering sheets were used in the experimental investigation. Figure 2 shows covering sheets used in this study. The permeable sheet consists of a drainage layer (nonwoven fabric) and a water-permeable layer (woven fabric). The sheet is water-permeable in addition to gas-permeable. The breathable-waterproof materials sheet consists of a breathable-waterproof film and reinforcing sheet (nonwoven fabric). The water-proof sheet is gas-permeable as well as the permeable sheet.

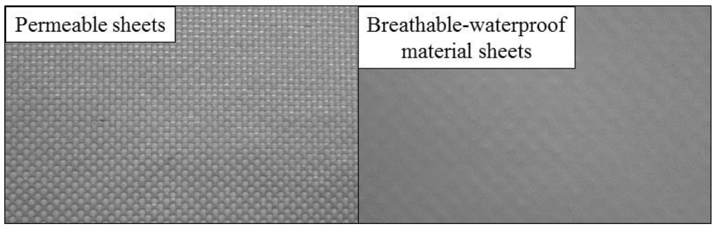
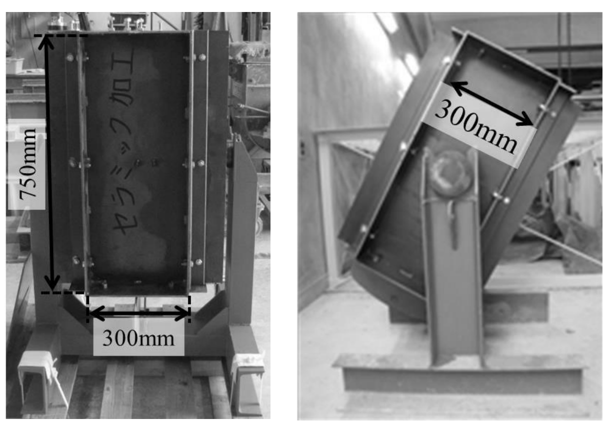


Figure 2. Surface of sheets.

2.2 Experimental Procedure

Seven concrete specimens, dimensions of 750 x 300 x 300 mm, were prepared to simulate conventional tunnel lining. Figure 3 shows a special concrete form used in this study. The steel plate for evaluation surface is replaceable to various plates. 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. Bug-hole distributions were observed and quantified by using an image analysis developed in this study. Herein, concrete surface of 300 x 300 mm was evaluated in the image analysis.



(a) Front view. (b) Side view.

Figure 3. Steel form simulated tunnel lining.

2.3 Experimental Program

The primary experimental parameters are (a) covering-sheet materials and (b) form surfaces such as ceramic-coated steel with grooves. The experiment parameters are described below. Seven specimens were made by using the plates shown in Figure 4.

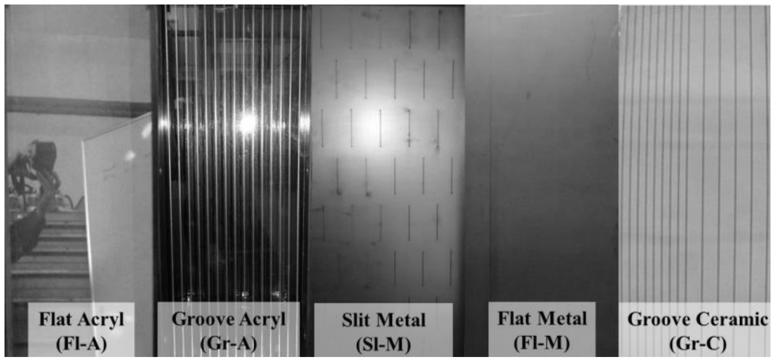


Figure 4. Steel and acryl plates used in the test.

2.3.1 *Covering-sheet materials*

In the experimental investigation, breathable-waterproof material sheets and permeable sheets were used to reduce the bug-holes on concrete. Both sheets are air permeable, and the latter sheet has no function of waterproof. A steel plate covering permeable sheets was set on the front surface of form. As well, an acrylic plate covering the breathable-waterproof material sheets were prepared. For comparison, concrete specimens were also made using the form without sheets.

2.3.2 *Form-surface*

Figure 5 shows a schematic of acrylic plate having grooves. To remove air efficiently from concrete surface, the acrylic plate has V-shaped grooves. The grooves of 2 mm width and 2 mm depth were arranged at an interval of 20 mm.

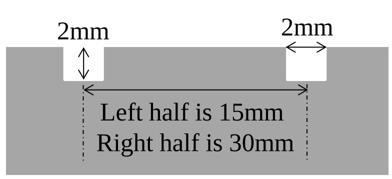


Figure 5. Grooves of the acryl form.

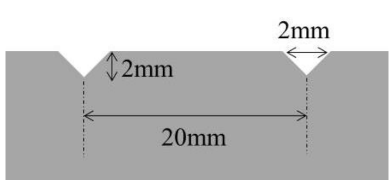


Figure 6. Grooves of the ceramic form.

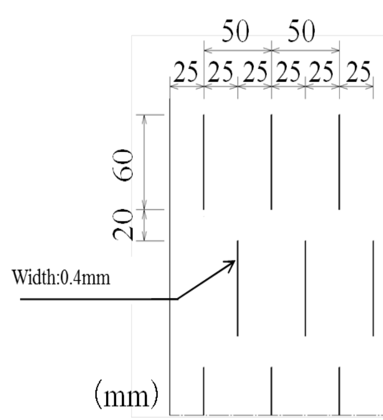


Figure 7. Slit arrangement of the steel plate.

Figure 6 demonstrates a schematic of ceramic-coated steel plate having grooves. Different from the acrylic plate, the cross sectional view of the groove is rectangular (2 x 2 mm) as shown in this figure. The grooves were made at interval of 15 mm (left) and 30 mm (right).

Figure 7 presents a detail of steel plate with slits. The slit, dimensions of 0.4 x 60 mm, was arranged at a horizontal interval of 50 mm and a vertical interval of 20 mm.

2.4 Evaluation Method for Bug-Holes

The experimental investigation examined bug-hole distributions by using an image analysis developed in this study. The measurement and quantification methods are summarized in below:

2.4.1 *Measurement system of bug-holes*

To measure quantity of bug-holes, colored images (took by a commercial digital still camera) are analyzed by using a special software developed in the study. RGB value of photographic image was used for the image analysis. The RGB value of a bug-hole in the photograph was employed as a criterion (reference value). The bug-holes are determined by using the difference of RGB values. Each pixel is analyzed, pixels with significantly different RGB value from the criterion are detected as a bug-hole. Compared to binarization method using black/white images, the image analysis employing RGB value is useful to detect small bug-holes (less than $5mm^2$). Furthermore, the measurement using the RGB value can reduce erroneous detection such as concrete stain, color-tone and shadows.

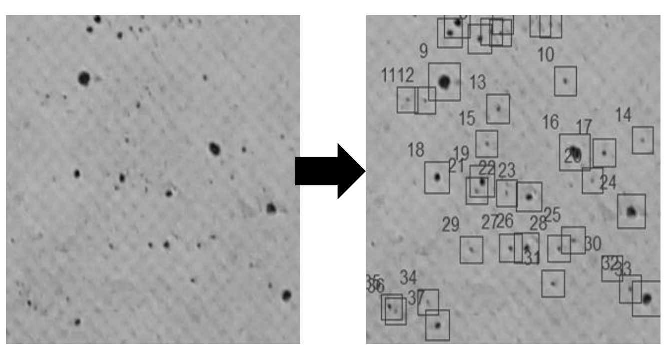


Figure 8. Image analysis process.

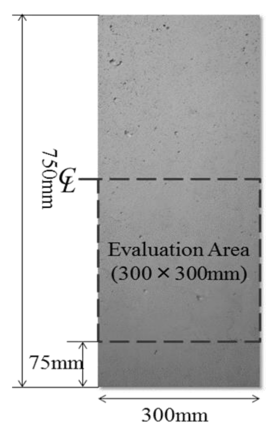


Figure 9. Evaluation area.

2.4.1 *Quantification of bug-holes*

Figure 8 illustrates an image analysis process. The boxes show bug-holes detected in the image analysis. Figure 9 demonstrates an evaluation area for the image analysis. The evaluation area was 300 x 300mm except for 75 mm from bottom end. Area-ratio of bug-holes is automatically calculated in the image analysis.

3 RESULTS AND DISCUSSION

Figure 10 shows that the area-ratio of bug-holes with using sheets (No.3, 4) has smaller difference than the ratio in the test without sheet (No.1, 2). In addition, the result shows that quantities of bug-holes using the sheets are lower than the quantity of bug-holes without sheets. It was noteworthy that the bug-holes were hardly observed in the test using form covered with the permeable sheet. The observation implies that the quantity of bug-holes can be decreased by using sheets. In particular, the result confirms that the permeable sheet is the most effective to decrease the bug-holes. It should be noted that the permeable sheet affects the color of concrete surface because of drainage effect.

The effect of the form-surface was not observed because of the effect of the permeable sheet (No.6, 7). In the tests using the breathable-waterproof material sheets, the area-ratios of bug-holes were varied by the form-surface.

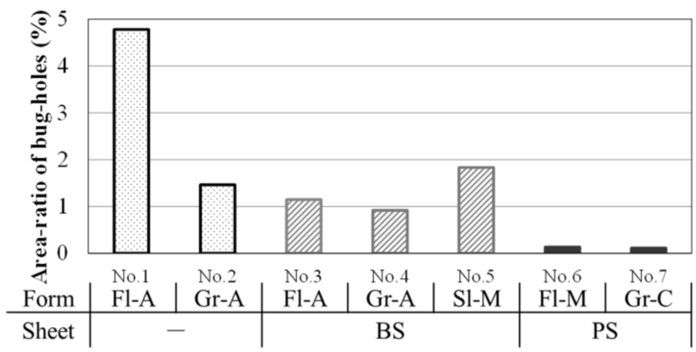


Figure 10. Area ratio of bug-holes.

4 CONCLUSIONS

The study focused on reduction of bug-holes distributed on concrete surface of tunnel lining. To reduce the bug-holes, covering sheets were used and the effect was examined. The findings in the experimental investigation are summarized below:

(1) The quantity of bug-holes of concrete using sheets is lower than the quantity of concrete without sheets.

(2) The permeable sheet is the most effective to decrease the bug-holes while it may negatively affect the color of concrete surface.

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