FUNDAMENTAL STUDY ON ESTIMATION METHOD FOR SURFACE ROUGHNESS OF CONCRETE CANAL GENERATED THE EXPOSURE OF COARSE AGGREGATE

Yuki HASEGAWA*, Choi MANKWON**, Koichiro OTAGAKI**,
Shinsuke MATSUMOTO***, Shushi SATO***
Graduate School of Integrated Arts and Science, Kochi University *
The United Graduate School of Agricultural Science, Ehime University **
Faculty of Agriculture, Kochi University ***

ABSTRACT**:** The surface of agricultural concrete canal was deteriorated by abrasion due to both water flow and sand in it. It is well known that progress mechanism of this type of abrasion starts from dissolution of cement paste, then coarse aggregates are exposing gradually. This phenomenon, exposure of coarse aggregate at the inner surface of canal, is considered to give bad affect to the hydraulic performance on transportation of planned flow as the increment of irregularity leads the loss of smoothness of concrete surface. However, the evaluation method of this deterioration has not established yet.

In this study, evaluation indexes on deterioration degrees of irregular surface were studied using the numerical information gotten from concrete surface. In addition, the application limit of image analysis was examined when the roughness of concrete surface was evaluated using three-dimensional image processing.
Porous concrete, its surface condition has enough roughness comparing with abraded surface of concrete canal, was applied for numerical expression of roughness of concrete surface on the assumption that the surface condition of porous concrete was similar to that of abraded concrete canal. Following three indexes concerned to roughness of concrete were focused in this study; arithmetical mean roughness “R_a”, maximum height “R_z” and Manning roughness coefficient which was used as an index of hydraulic performance.

As a result, it was indicated that “R_z/D”, divided maximum height “R_z” with maximum size of coarse aggregate “D”, could be used as the index of deterioration degree if the coarse aggregate were falling off from concrete surface when the abrasion depth of concrete canal was progressing to “R_z”. Furthermore, it was clarified that analytical estimation of surface roughness using three-dimensional image processing was effective when focusing to the roughness coefficient. Therefore it was considered that hydraulic performance of concrete canal could be estimated simply using three-dimensional image processing.

KEYWORDS: concrete canal, abrasion, exposure of coarse aggregate, surface roughness, three-dimensions image processing

1. INTRODUCTION

The irrigation and drainage facilities are one of the important social infrastructures to support stable production of food. Agricultural irrigation canals whose total lengths are about 400,000 km in Japan are important social stocks as they contribute to transport the essential water for agriculture. Most of the agricultural canals are made of concrete. However, various deteriorations are progressing in actuality due to the advance of passage of service periods, similar with general civil concrete structures. Major deteriorations of concrete structure are neutralization, salt damage, frost damage, ASR, abrasion and fatigue. In these deteriorations, abrasion generated in concrete canal is considered to be a problem up to now in Japan. Abrasion progressing form surface of concrete canal is caused by water flow and sand in water flow, and this deterioration is considered to affect to hydraulic performance of concrete canal.

When abrasion progresses at the concrete canal, a part of mortar is disappeared from concrete surface at first. Then coarse aggregates are exposing gradually. Actual surface condition of concrete canal generated the exposure of coarse aggregate is shown at **Fig.1**. Abrasion is considered to give bad affect to hydraulic performance on transportation of designed flow because the increment of irregularity generates the loss of smoothness of concrete surface. However, verification method and performance index for quantitative evaluation in order to decide the deterioration degrees of abrasion in concrete canal has not established yet.

It is necessary to measure surface roughness of canal quantitatively for the purpose of accurate evaluation on deterioration degrees of concrete canal generated the exposure of coarse aggregate. Several measurement methods using such as laser displacement sensor and profiling gauge have been

Fig.1 Concrete canal generated exposure of coarse aggregate

proposed in some reports (Homma et al. 2008, 2009). However, most of the measurement requires special equipments and techniques, or long working hours. To conduct efficient maintenance and management against the huge number of canal, development of more convenient and higher accuracy on measurement method are necessary in the near future.

In this study, evaluation indexes on deterioration degrees of concrete canal generated the exposure of coarse aggregate were studied using the numerical information gotten from concrete surface. In addition, quantitative evaluation of surface roughness using three-dimensional image processing was examined as a simple measurement method for concrete surface.

2. SUMMARY OF EXPERIMENT

2.1 Outline of Specimen

In this study, porous concrete specimens (called PCS, here after) were used as the measurement subject. In general concrete, coarse aggregate of continuous grading are used and mortar are filled up almost completely between the voids of each coarse aggregate. On the other hand, porous concrete is made using same particle size of coarse aggregate as well the fine aggregate is suppressed extremely. Each coarse aggregate in porous concrete is joined as if each coarse aggregate is joined at the point contact with surrounding cement hydrations. Thus, matrix

Table 1 Detail of used PCS

Specimen name	Crushed stone size	Particle diameter (mm)	Total porosity (%)
No. 5 (22.3)	No. 5	13 ~ 20	22.3
No. 6 (25.7)	No. 6	5 ~ 13	25.7
No. 7 (18.9)	No. 7	2.5 ~ 5	18.9
No. 7 (20.5)	No. 7	2.5 ~ 5	20.5
No. 7 (22.7)	No. 7	2.5 ~ 5	22.7

Fig.2 Photographs of PCS using several crushed stone size

structure of porous concrete has lots of void and its surface is rougher than general concrete. Therefore, it was considered that the surface of porous concrete could be assumed as the concrete canal generated the exposure of coarse aggregate. In this study, 5 types of PCS made with different size of crushed stone and void ratio were prepared. The detail contents and photographs of used PCS were shown in **Table 1** and **Fig.2**, respectively. Size of every specimen is 23cm×23cm×6cm with its height, length and width.

2.2 Evaluation method of surface roughness

2.2.1 Measurement by laser displacement sensor

Procedure of estimation on surface roughness is described as follows:

(1) Measure the transversal lines of each specimen.

(2) Gain the roughness curve converted after corrected the inclination of measured transversal lines.

(3) Calculate the parameters concerns to surface roughness from roughness curve.

In this study, laser displacement sensor (high speed, high accuracy CCD laser displacement sensor LK – G155, KEYENCE Co. Ltd) was used to measure the transversal lines. This measured value was assumed to the actual value. The number of transversal lines was 40 at each specimen.

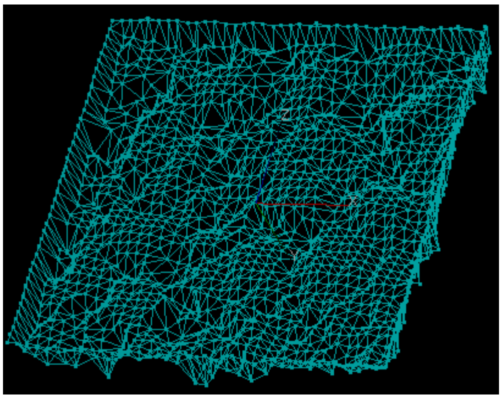

Fig.3 Surface of reproduced PCS by Kuraves-K

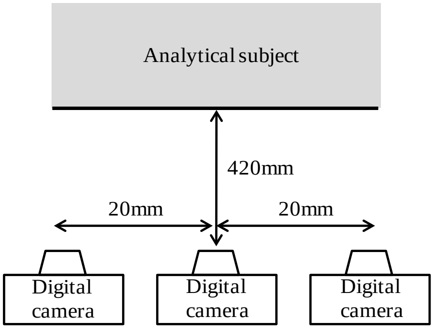

Fig.4 Simple figure of photography method

2.2.2 Evaluation method using three-dimensional image processing

Three-dimensional image processing software (Kuraves-K, KURASIKIBOSEKI Co. Ltd) was used in this study. This software has a function to convert three pictures of the stereo structure of the subject into three dimensional numerical data. An example of processing result was shown in **Fig.3**. Kuraves-K can process with regardless of model or performance of used digital camera. In addition, operation at the job site can be very simple; just get three images of the subject. That is, it was considered that stable evaluation on surface roughness could get in spite of the technique level of workers. An effective pixel of used digital single-lens reflex camera (α380, SONY Co. Ltd) in this study is 14.2 million pixels. A simple figure of photography method is shown in **Fig.4**. When taking images, a focal distance is fixed into 420mm, and 20mm is moved horizontally from center to both left and right sides. Three images were taken from each subject.

In this study, subject area of image processing is set into 100mm×100mm square; this cross section was decided because most of the maximum size of coarse aggregate for general concrete canal is about 20 to 25mm. Moreover, processing result was stable in 100mm×100mm at preparatory experiment used a typical model of rough surface of concrete. The number of element was set into 1600 points (40×40 points) considering accuracy of the previous preparatory experiment. The number of transversal lines was 40 at each specimen as same as actual value. From a comparison of the data on actual value and processing value, suitability of evaluation using three-dimensional image processing against concrete canal generated exposure of coarse aggregate was studied.

2.3 Examined indexes of surface roughness

Maximum height "R_z" (sum of the gap between maximum and minimum point from average line of the roughness curve) and arithmetical mean roughness "R_a" (average on modulus of gap from average line of roughness curve) were calculated from the same roughness curve as quantitative indexes of surface roughness. A conceptual figure of R_z and R_a was shown in **Fig.5**. Indexes of each value were averaged of 40 transversal lines in similar method with actual value.

2.4 Estimation on influence of exposure of coarse aggregate to hydraulic performance

Generally, roughness coefficient "n" in Manning's average velocity formula is used as the index of hydraulic performance of concrete canal. Roughness coefficient is also considered to be the index which can reflect well the friction influence of wall surface. Roughness coefficient is considered to increase when surface roughness of concrete is increased. In common, roughness coefficient is calculated from water depth, velocity, and a flow of the canal. However, in recent years, some study has attempted that roughness coefficient is estimated from surface roughness of concrete indirectly (Nakaya et al. 2008). In this study, roughness coefficient was estimated using R_z and R_a referred to the above study. Firstly, equivalent roughness "k_s" was calculated using R_z and R_a from eq. (1) and (2).

$$k_s = 0.26 \times R_z \quad (1)$$

$$k_s = 2 \times R_a \quad (2)$$

Secondly, roughness coefficient was calculated using Manning-Strickler formula shown at following eq. (3).

$$n \approx 0.13 \frac{k_s^{1/6}}{\sqrt{g}} = 0.042 k_s^{1/6} \quad (3)$$

where n is Manning's roughness coefficient (s/m$^{1/3}$), and g is gravitational acceleration (m/s^2).

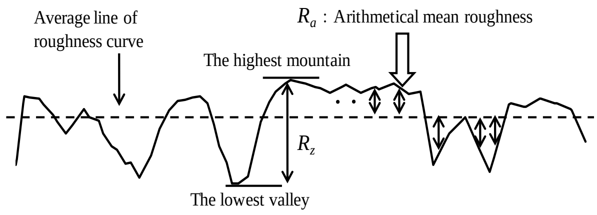

Fig.5 Conceptual figure of R_z and R_a

3. RESULTS AND DISCUSSIONS

3.1 Estimation indexes of deterioration degrees based on the actual measurement values

Indexes for evaluating the deterioration degrees of concrete canal generated the abrasion quantitatively were studied here after. Parameters on surface roughness calculated from actual measured data using laser displacement sensor were shown in **Table 2**. In this table, μ is the average of 40 data and σ is the standard deviation of them. In addition, "R_{z1}/D", average of R_{z1} divided with maximum size of coarse aggregate "D" used in each specimen, was evaluated as well as R_{z1} and R_{a1}.

From the **Table 2**, it was confirmed that averages of R_{z1} and R_{a1} increased due to the size of crushed stone used in each specimen. Observing the variation of standard deviation σ, it was indicated that different parameters of surface roughness were estimated depending on the positions of transversal line. Therefore, following two subjects were revealed to solve for the practical use; how the measurement points as well as the size of sample were decided in the member.

Focus on R_{z1}/D of all specimens, it was confirmed that the range of R_{z1}/D was within 0.66±0.09. In general, the coarse aggregate in concrete starts falling off when the abrasion depth of concrete canal is progressing to "R_z". It means coarse aggregate starts falling off from concrete surface when R_z/D become larger than 1. On the other hand, R_z/D values obtained from PCS in this experiment were all included within 0.66±0.09. As each coarse aggregate in porous concrete joined very close to the condition of spot adhesion, coarse aggregates are exposed almost completely. If surface of concrete canal become like that of porous concrete due to the abrasion, coarse aggregate in general concrete would be fallen off because there were no points of contact between each coarse aggregate. Therefore, it was considered that coarse aggregates would fall off in general concrete canal when R_z/D is larger than 0.66±0.09. This value would be a threshold of the lowest limit for the diagnosis of deterioration degree of concrete canal generated the exposure of coarse aggregate.

Table 2 Parameters of surface roughness by actual measurement data

Specimen name		R_{z1}	R_{a1}	R_{z1}/D
No. 5 (22.3%)	μ	15.035	2.831	0.752
	σ	4.080	0.697	
No. 6 (25.7%)	μ	9.488	1.627	0.730
	σ	2.147	0.313	
No.7 (18.9%)	μ	3.434	0.466	0.687
	σ	0.719	0.094	
No.7 (20.5%)	μ	2.836	0.333	0.567
	σ	0.585	0.071	
No. 7 (22.7%)	μ	3.651	0.525	0.730
	σ	0.837	0.088	

3.2 Examination on accuracy of analysis

Accuracy of analysis was identified with the comparison between actual data and analyzed data using Kuraves-K. Calculated parameters of surface roughness using actual measured data and processing data were shown in **Table 3**. In this table, R_{z1} and R_{a1} meant actual values as well R_{z2} and R_{a2} meant analytical values. In addition, index for the reproducibility was calculated with following

Table 3 Calculated parameters of surface roughness using actual measurement and processing

		Actual value		Analytical value		Reproducibility	
Specimen name		R_{z1}	R_{a1}	R_{z2}	R_{a2}	R_{z2}/R_{z1}	R_{a2}/R_{a1}
No. 5 (22.3%)	μ	15.035	2.831	9.336	1.670	0.621	0.590
	σ	4.080	0.697	2.201	0.500		
No. 6 (25.7%)	μ	9.488	1.627	5.874	0.999	0.619	0.614
	σ	2.147	0.313	1.084	0.195		
No.7 (18.9%)	μ	3.434	0.466	2.244	0.399	0.654	0.856
	σ	0.719	0.094	0.567	0.099		
No.7 (20.5%)	μ	2.836	0.333	2.164	0.372	0.763	1.118
	σ	0.585	0.071	0.505	0.055		
No. 7 (22.7%)	μ	3.651	0.525	2.820	0.493	0.772	0.938
	σ	0.837	0.088	0.567	0.074		

Table 4 Converted roughness coefficient

	Actual value		Analytical value		Reproducibility	
Specimen name	$n_1(R_{z1})$	$n_1(R_{a1})$	$n_2(R_{z2})$	$n_2(R_{a2})$	$n_2/n_1(R_z)$	$n_2/n_1(R_a)$
No. 5 (22.3%)	0.0167	0.0177	0.0154	0.0162	0.924	0.916
No. 6 (25.7%)	0.0154	0.0162	0.0143	0.0149	0.923	0.922
No.7 (18.9%)	0.0130	0.0131	0.0121	0.0128	0.932	0.974
No.7 (20.5%)	0.0126	0.0124	0.0121	0.0127	0.958	1.025
No. 7 (22.7%)	0.0132	0.0134	0.0125	0.0132	0.952	0.983

process; average μ of analytical value were divided with average μ of actual value at each specimen.

It was confirmed that reproducibility of R_z in all specimens were converged within the range of 0.70±0.08. On the other hand, while R_{z1} was 15.035mm at No.5 (22.3%), R_{z2} was 9.336mm. Consequently, it was difficult to express the exact void depth of PCS accurately by image processing. Therefore, it was considered that R_z of analytical value and R_z/D used analytical value were difficult to apply as the index of deterioration degrees. On the contrary, reproducibility of R_a was varied significantly at every specimen. Especially, highly reproducibility was confirmed at all void ratios of specimens used No.7 of crashed stone size. Therefore, R_a gotten from image processing was possible to be an index to diagnose the deterioration degrees when the surface roughness was equal to the specimens using No.7 size of crashed stone.

From these results above, it was concluded that highly reproducibility were confirmed while actual value of R_a were within 0.333mm to 0.525mm when Kuraves-K was used to diagnose for deterioration degrees against concrete canal generated the exposure of coarse aggregate. On the contrary, reproducibility of R_z was lower comparing with that of R_a at all specimens. The reason was considered that the depth of void of PCS was impossible to reproduce accurately by the capability of image processing.

3.3 Evaluation of hydraulic performance focused on roughness coefficient

R_z and R_a were converted into coefficient of Manning's roughness using actual and analytical values, respectively. Converted roughness coefficients were shown in **Table 4**. $n_1(R_z)$ and $n_1(R_a)$ meant the converted roughness coefficient using actual value, and $n_2(R_z)$ and $n_2(R_a)$ meant the converted roughness coefficient using analytical value. In addition, index for the reproducibility was calculated with following process; the converted roughness coefficient using analytical value were divided with the converted roughness coefficient using actual value each specimen.

Reproducibility was higher than 0.93 at all void ratios of specimens used No.7 size of crashed stone. The maximum difference between n_1 and n_2 was only 0.0009. Generally, roughness coefficient is used with the third decimal point as minimum digit of significant figures. So, the above difference was considered to be too small to mention on it. Furthermore, reproducibility using R_a was higher than that using R_z. Thus, to convert roughness coefficient using analytical value, R_a was comfortable rather than R_z.

Reproducibility of No.5 (22.3%) and No.6 (25.7%) were about 0.92, lower than that of PCS used No.7 size of crushed stone. However, the maximum difference between n_1 and n_2 was only 0.0015.

Mentioning the effective digit explained at above section, this difference of roughness coefficient was considered to be small. Therefore, converted roughness coefficient used analytical value could express approximately to that used actual value of No.5 (22.3%) and No.6 (25.7%).

From these results, roughness coefficient calculated using analytical value by Kuraves-K was confirmed to have highly reproducibility against all specimens used in this study. Therefore, it was concluded that roughness coefficient of concrete canal generated the exposure of coarse aggregate could be evaluated accurately applying the image processing using Kuraves-K.

4. CONCLUSIONS

In this study, parameters that could be an index of deterioration degrees on concrete canal generated the exposure of coarse aggregate were examined. Moreover, the accuracy of evaluation method using three-dimensional image processing was studied as simply estimation method for surface roughness. The results obtained in this study were summarized as follows:

1) 0.66±0.09 of R_z/D would be a threshold of the lowest limit for the diagnosis of deterioration degree on abrasion of concrete canal.

2) Reproducibility of R_z was low because the depth of void of PCS was impossible to reproduce the surface conditions of concrete accurately due to the capability of image processing.

3) Highly reproducibility was confirmed while actual value of R_a was within 0.333mm to 0.525mm.

4) The roughness coefficient could be evaluated applying the image processing using Kuraves-K.

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