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MEASUREMENT OF ARITHMETICAL MEAN ROUGHNESS OF CONCRETE BY TRANSCEIVER TYPE AERIAL ULTRASONIC SENSOR

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ABSTRACT: The roughness coefficient of the concrete irrigation canal is one of the important evaluation criteria to ensure the hydraulic performance or malfunction between water and wall surface. In this study, the roughness coefficient of the concrete irrigation canal was measured using the aerial ultrasonic wave of the transceiver type sensor. The effect of the dispersion of measurement values in relation to the arithmetical mean roughness and the peak to peak value of the reflected wave were demonstrated. The influence of wet and dry conditions of concrete surface and the verification of the measurement range were taken into account. Results obtained showed that the peak to peak value of the reflected wave could measure the arithmetical mean roughness of concrete. It was observed that the average of 15 measured values was sufficient for accuracy. The peak to peak value of the reflected wave was affected slightly under wet condition. The range of the measured diameter of aerial ultrasonic wave sensor was approximately 300 mm and 600 mm from the distance of 550 mm and 1000 mm respectively. It is concluded that the development of the measurement method of arithmetical mean roughness of concrete surface by the transceiver type aerial ultrasonic sensor can be achieved.

Keywords: Aerial ultrasonic, Peak-to-peak value, Arithmetical mean roughness, Hydraulic performance, Functional diagnostic

1. INTRODUCTION

Japan has possessed many concrete irrigation canals mainly used for agriculture that have a total length of 49,239 km. These were constructed in the high economy era of 1954-1973. As the canals age, it becomes necessary for them to be repaired. In particular, hydraulic performance malfunctions are considered strong indicators that repair is needed. During general maintenance, visual inspection is often used to evaluate the roughness of canal surfaces. Some canal managers want to quantitatively assess the value of the concrete surface roughness of canals. As agricultural irrigation canals have enormous length, the quantitative assessment method must be simple, quick, and economical.

Decreased flow velocity and increased water level are related to the concrete surface roughness. The roughness coefficient is used as one of the evaluation criteria for concrete irrigation canal hydraulic performance malfunctions. The arithmetical mean of the concrete surface roughness is used to estimate the roughness coefficient. However, a simple, rapid, and economical measurement of the arithmetical mean roughness is difficult.

Over the years, considerable attention has been paid to the study of the measurement of the arithmetical mean roughness. Scientists have proposed the following methods to measure it.

Sand Patch Test: This is one of the most commonly used methods for examining the macrotexture depth of concrete surfaces. This direct volumetric method consists in careful application of a given volume of granular material (glass spheres or sand) of a given granularity onto a surface and subsequent measurement of the total area covered. The sand patch test is exposed to a large probability for human error: it is a test that cannot be performed quickly without comprising accuracy [1], [2].

Concrete Surface Profiles: In this method, the prepared surface is compared by visual inspection with nine standard concrete surface profiles of increasing roughness [3].

Outflow Meter: This is a volumetric method used to assess the surface roughness of asphalt and concrete road pavements. The method yields an average value for the surface roughness but no other information [1], [4].

Moulage Gauge Method: This method measures the arithmetical mean roughness by a simple measurement method that only requires a manager to press a moulage gauge onto the concrete surface. However, a complicated analysis is needed that reads displacements from the moulage gauge one by one [5], [6].

Laser Displacement Sensor Method: This method measures the arithmetical mean roughness with a measurement range that is the line information of the concrete surface. This method has a high precision, but is costly for measuring irrigation canals [7-10].

This study investigated the measurement of the arithmetical mean roughness by using a transceiver-type aerial ultrasonic sensor. The wave of the aerial ultrasonic sensor has a characteristically wide spread. The experimental data were acquired by an oscilloscope at a rate of 25 measurements per second. This method has the potential to enable a simple, quick, and economical quantitative assessment.

The dispersion of the measurement values, the relationship between the peak-to-peak value and the arithmetic mean roughness, and the influences of wet and dry concrete surfaces were investigated, and the measurement range was verified.

2. MEASUREMENT EQUIPMENT

The LZ-Maxsonar-EZ1 transceiver-type aerial ultrasonic sensor (MaxBotic, Inc.) was designed for ultrasonic distance measurements. The frequency was selected based on attenuation in air: Because an ultrasonic wave with frequency higher than 80 kHz attenuates within a distance of 2000 mm and one with frequency lower than 20 kHz may enter the audible range, the selected frequency was about 40 kHz. An ultrasonic wave of 40 kHz can be measured from a distance of about 500–2000 mm with little attenuation. Next, open-type (sensitivity: min. -80.5 dB) and waterproof-type (sensitivity: min. -58.2 dB) sensitivities were compared. The open type sensitivity was 13 times higher than the waterproof type at each output voltage, so the open type was selected. However, measurement of the aerial ultrasonic wave must be limited so as not to get wet. Other specifications are shown in Table 1. Experimental data of the peak-to-peak values were acquired by a digital oscilloscope TBS1152 (Tektronix, Inc.).

Table 1 Specifications of the transceiver-type aerial ultrasonic sensor

Frequency		42	kHz
Dimensions	A	16.4	mm
	B	15.5	mm
	C	19.9	mm
	D	22.1	mm
Mass		4.3	grams

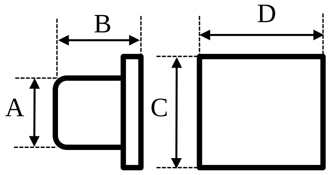

Fig. 1 The aerial ultrasonic sensor

3. MEASUREMENT PRINCIPLE

Fig. 2 shows the principle of measurement of concrete surface roughness by using an aerial ultrasonic sensor of the transceiver type. An aerial ultrasonic wave is diffusely reflected by the roughness of the concrete surface. The peak-to-peak value (mV) of the reflected wave is evaluated. The peak-to-peak value is the difference between the maximum and the minimum voltage levels (mV) of the reflected wave.

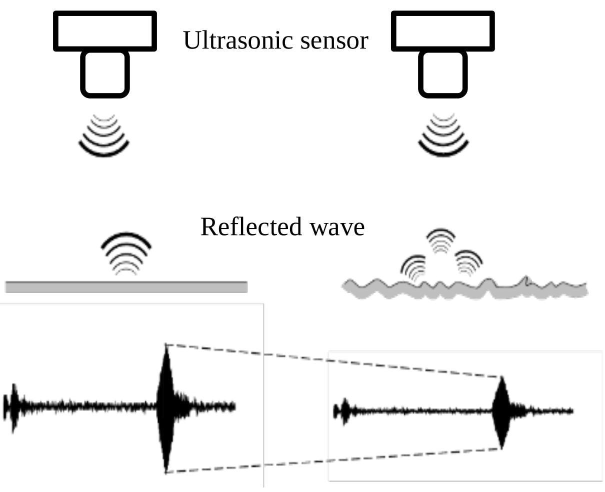

Fig. 2 Measurement principle of the ultrasonic sensor

4. ARITHMETICAL MEAN ROUGHNESS

4.1 The Moulage Gauge and Roughness Determination

The arithmetical mean roughness was measured by a moulage gauge. The length of the moulage gauge was 147 mm, and the number of steel sticks was 183. The measurement interval was 0.8 mm. Fig. 3 shows a measurement surface with an arithmetical mean roughness of 0.30 mm.

Fig. 4 shows an example of the determination of the arithmetical mean roughness, where $\boldsymbol{f}_{(x)}$ is the roughness curve of the concrete surface and $\boldsymbol{Y}_{(x)}$ is a linear approximation that is calculated from the roughness curve.

The value of $\boldsymbol{R_a}$ is calculated by the ratio of the integral value of $|\boldsymbol{f}_{(x)} - \boldsymbol{Y}_{(x)}|$ and the length of the moulage gauge:

$$\boldsymbol{R_a} = \frac{1}{l}\int_0^l \left|\boldsymbol{f}_{(x)} - \boldsymbol{Y}_{(x)}\right| \boldsymbol{d}_{(x)} \qquad (1)$$

$\boldsymbol{R_a}$: Arithmetical mean roughness
$\boldsymbol{f}_{(x)}$: Roughness curve
$\boldsymbol{Y}_{(x)}$: Linear approximation
$\boldsymbol{l}$: Length of the moulage gauge

Fig. 3 Measurement surface with arithmetical mean roughness of 0.30 mm

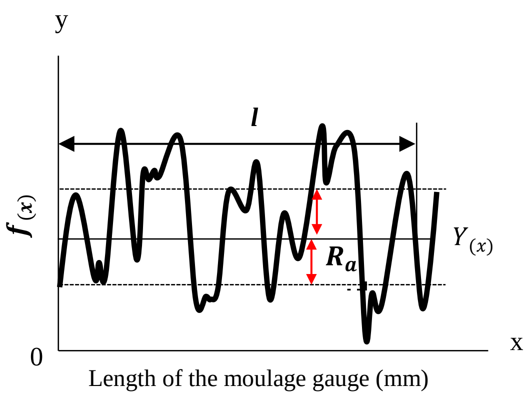

Fig. 4 Example of arithmetical mean roughness determination

4.2 Selected Measurement Surface

Kitamura et al [5] describes the relationship between the arithmetical mean roughness and the age of agriculture irrigation canals. When an agriculture irrigation canal has been used for 40 years, the arithmetical mean roughness becomes approximately 0.7 mm. The selection was done by considering the soundness of the canal. Table 2 lists the examination items and the arithmetical mean roughness.

Table 2 Examination items and the arithmetical mean roughness

R_a (mm)	Dispersion	Application	Wet
0.00		○	
0.30	○	○	○
0.37		○	
0.45	○	○	○
0.67		○	

5. EXAMINATION ITEMS

5.1 Dispersion of Measurement Values

Measurements by an aerial ultrasonic sensor become dispersed. Therefore, the dispersion of the measurement values needs to be decreased by time averaging. The purpose of this experiment is to determine the best way to average the times of the measurement values.

The peak-to-peak value was measured 119 times in same arithmetical mean roughness. We obtained 100 samples of the moving average of 1 to 20 time measurements. The ratio of the standard deviation and the mean value of the moving average was evaluated. The aerial ultrasonic waves were measured from distances of 1000 and 550 mm.

Fig. 5 shows that the dispersion of the measurement value decreased as the arithmetic average increased. The dispersion of the measurement values for 550 mm tended to be larger than for 1000 mm. However, the arithmetic averages of 15 time measurements restrained the dispersion of the measurement values for 550 and 1000 mm. An average of 15 time measurement values yields sufficient accuracy. In this study, the measurement value is defined as the average of 15 values..

5.2 Application of Measurement of the Arithmetical Mean Roughness

The peak-to-peak values were measured, aerial ultrasonic waves were measured from a distance of 1000 mm, and the arithmetical mean roughness was measured for five concrete surfaces with a range of

0.00 to 0.67 mm.

It is clear from Fig. 6 that the peak-to-peak values decreased with increasing arithmetical mean roughness. In addition, the linear approximation was high correlated, and it was used to estimate the arithmetic mean roughness from the peak-to-peak value. Measurements of transceiver-type aerial ultrasonic waves can be used to accurately estimate the arithmetical mean roughness.

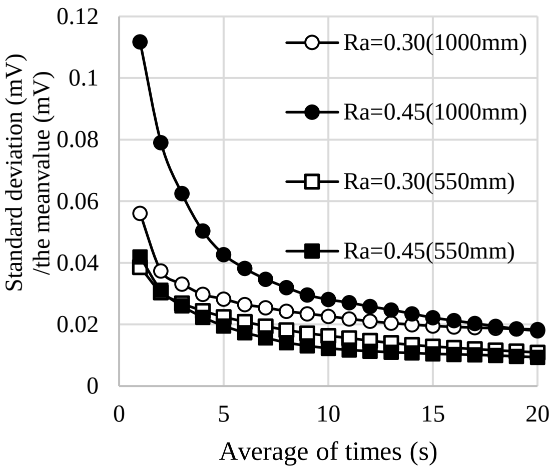

Fig. 5 Dispersion of the measurement values

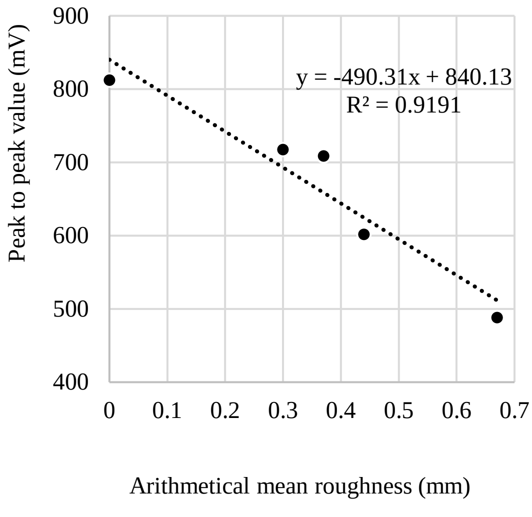

Fig. 6 Relationship between the peak-to-peak values and the arithmetical mean roughness

5.3 Effect of Wet and Dry conditions of Concrete Surfaces

Managers measure agriculture irrigation canals during non-irrigation periods when the water level is lower. However, in case of rainy day, evaluation was done on the basis of wet conditions of the concrete surface. The measurement values of wet and dry concrete surfaces were compared. When wet conditions of the concrete surface were reproduced, water pockets were noted in the roughness depressions. The aerial ultrasonic waves were measured from distance of 1000 mm.

Table 3 shows the measurement values for wet and dry concrete surfaces. The measurement value for wet was slightly larger than dry. It was considered that water filled the roughness depressions of the concrete surface, which decreased the arithmetical mean roughness. However, Fig. 5 shows that the standard deviation of the arithmetic average of 15 time measurements from a distance 1000 mm was ±15.7 mV. Because the difference between the measurement values was within the range of the standard deviation, it was observed that whether the concrete surfaces are wet or dry does not significantly influence the measurement value. Fig. 7 shows reflected waveforms from wet and dry concrete surfaces, and it can be seen that the waveforms are not different. Hence, the measurement value of the reflected wave was little affected by wet conditions.

Table 3 Measurement values for wet and dry surfaces

	Wet (mV)	Dry
R_a=0.30 (mm)	717.6	704.4
R_a=0.45	601.5	590.1

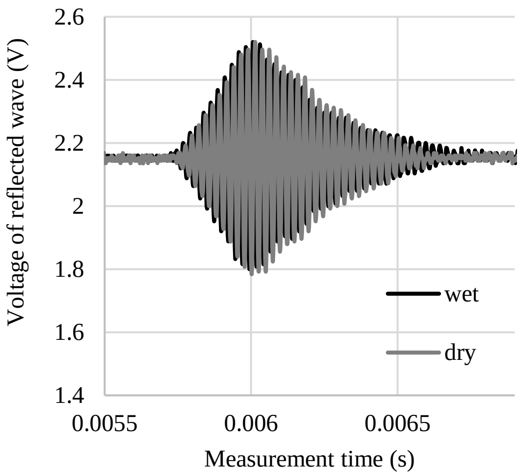

Fig. 7 Reflected waveforms from wet and dry concrete surfaces in R_a=0.30 mm

5.4 Verification of Measurement Range

Aerial ultrasonic waves can be measured over a wide range. However, the influence of the measurement range is uncertain. Fig. 8 demonstrates the experimental principle. The measurement range was investigated by widening the diameter of gravel spread on a flat board. The arithmetical mean roughness of the flat board was 0.00 mm and the particle size of the gravel of was 2 mm. Fig. 9 depicts how the gravel was used. The aerial ultrasonic waves were measured from distances of 1000 and 550 mm.

Figs. 10 and 11 show that the measurement values decreased with widening diameter of the gravel area. Fig. 10 reveals the relationship between the peak-to-peak value and the gravel diameter. With a gravel area diameter of 200 mm, the peak-to-peak value decreased markedly. Between 200 and 400 mm, the peak-to-peak decreased slowly. After 600 mm it did not change. Because a 600 mm gravel diameter presumably exceeds the measurement range, the upper limit of the measurement range is approximately 600 mm in diameter.

Fig. 11 shows the relationship between the peak-to-peak value and the gravel diameter from a distance of 550 mm. With a gravel diameter of 200 mm, the peak-to-peak decreased by a large amount. Between 200 and 300 mm, the decrease was much less. After 300 mm the value did not change. Because a 300 mm gravel diameter presumably exceeds the measurement range, the upper limit of the measurement range is approximately 300 mm in diameter.

The dominant range of measurement is approximately 200 mm in diameter from distances between 550 and 1000 mm.

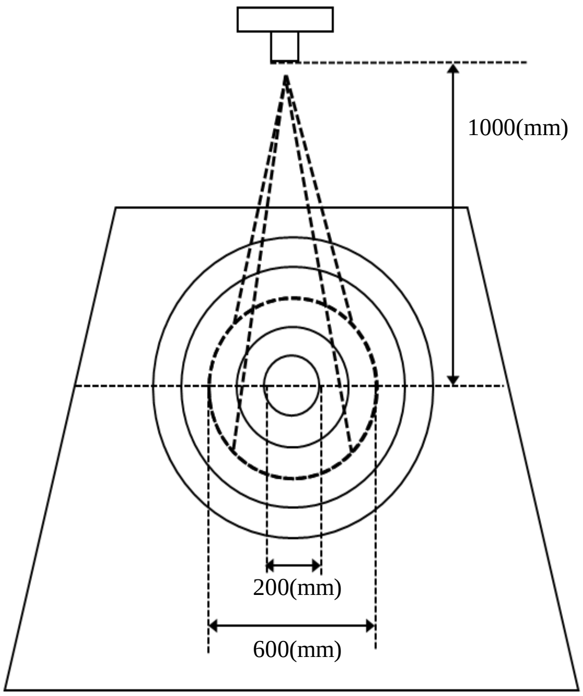

Fig. 8 The experimental principle for verification of the measuring range

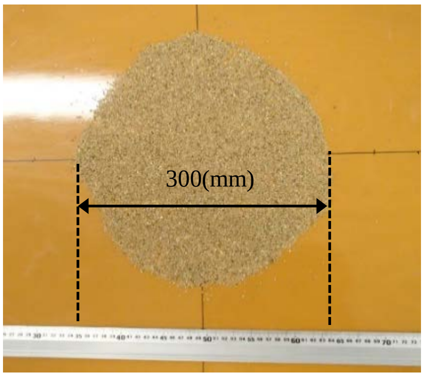

Fig. 9 Gravel-use for the verification of measurement range

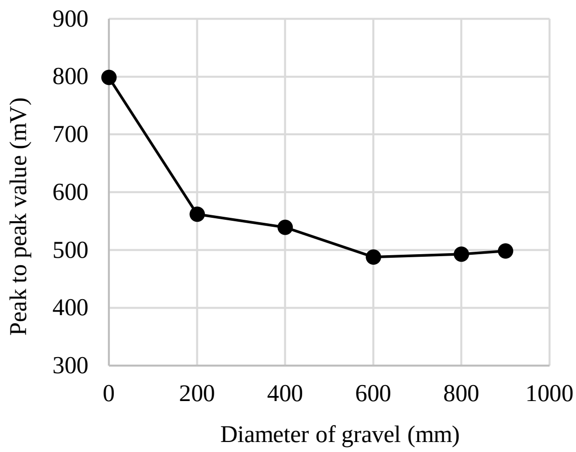

Fig. 10 The relationship between peak-to-peak value and diameter of gravel from distance of 1000 mm

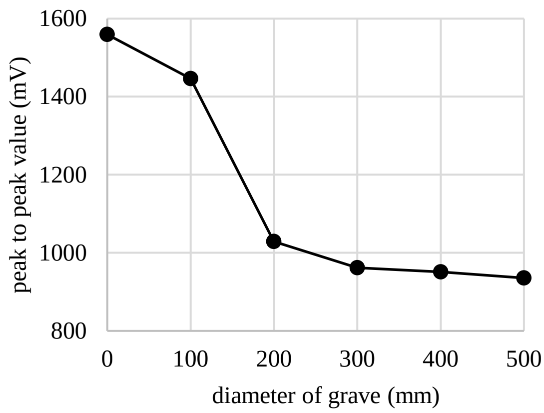

Fig. 11 The relationship between peak to peak value and diameter of gravel from distance of 550 mm

6. CONCLUSION

The influence of the dispersion of the measurement values, the relationship between the arithmetical mean roughness and the peak-to-peak value of the reflected wave, the influence of wet and dry concrete surfaces, and verification of the measurement range were investigated. As a result, the following points became clear. The peak-to-peak value of the reflected wave can be used to estimate the arithmetical mean roughness well. An average of 15 time measurement values resulted in sufficient accuracy. The peak-to-peak value of the reflected wave was not strongly affected by wet conditions. The aerial ultrasonic waves were measured with diameters of approximately 600 and 300 mm from distances of 1000 and 550 mm, respectively. The dominant range of measurement was 200 mm in diameter from distances of 550 to 1000 mm.

To estimate the arithmetical mean roughness, a manager needs only to evaluate the peak-to-peak value of the reflected wave, and the measurement can be confidently performed when the concrete surface is wet and over a wide measurement range. This study demonstrates that it is possible to develop a method to measure the arithmetical mean roughness of the concrete surface by a transceiver-type aerial ultrasonic sensor. It remains a challenge for future research to verify such measurements under various weather conditions, different temperatures and wind velocities.

7. ACKNOWLEDGEMENTS

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8. AUTHOR’S CONTRIBUTIONS

Author 1: Conception, design, acquisition, analysis and interpretation of data and drafting the article. Author 2: Collection and assembly of data. Author 3: Conception and design of the study. Author 4: Final approval of the article and design of measurement surface. Author 5: Collection of data and advice of hydraulics. Author 6: Create of measurement surface and experiment material. Author 7: Advice of the aerial ultrasonic sensor.

9. ETHICS

This article is an original work and not under consideration for publication in any other journal. There are no conflict of interest on this paper.

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