VOL. 7, NO. 8, AUGUST 2012 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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INTERNAL CRACK ASSESSMENT ON CONCRETE STRUCTURES BY SCANNING IMAGE ANALYSIS

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ABSTRACT

Request for the development of non-destructive test (NDT) techniques have improved with the growing concern about the deteriorating condition of concrete structures. Efficient and accurate imaging techniques are needed for a reliable evaluation on safety and serviceability of concrete structures. Although, presently, imaging is routinely conducted in various fields, implementation of these technologies in NDT of civil engineering systems, especially on concrete structures, offers many challenges and requires additional development due to the composite nature of the concrete material and the complexities of reinforced concrete systems. In this paper, the feasibility of visual observation device that developed with small inspection borehole for investigating internal crack in concrete structure by scanning technique is presented. Special considerations regarding the applicability and accuracy of these techniques for the condition assessment of concrete structures are discussed, and examples of field application are given.

Keywords: concrete, internal crack, scanning image, small-scale destruction, plural information.

1. INTRODUCTION

Concrete is a composite material consisting of a binding medium with particles like gravel, sand etc. embedded in the construction medium. Critical concrete structures need to be evaluated during their service to ensure that they have not deteriorated and are free from defects. Referring to the practice of the 20th century and analyzing the modern tendencies it is possible to say with reasonable confidence that the reinforced concrete was, still is and will be one of the basic construction materials (Grosse, *et al*., 2006). This material is used to construct buildings, bridges, tunnels, nuclear reactors and other structure, its extensive use requires development of corresponding diagnostics methods and means. So it is necessary to build instruments and develop procedures providing estimation of a structures condition and to determine its remaining service life.

In Japan, there is an indication that structure maintenance for 50 years old construction is rapidly increasing in the last decade. For that reason, an assessment condition of structure member becomes an important aspect to determine a repair plan of aged structural system and establish the durability. The purpose of inspection is to grasp the performance of a structure and collect information necessary for carrying out maintenance. Inspection shall be carried out by suitable methods to discover deterioration, damage, or initial defects and to maintain the performance of the structure above the required level. In the cases when any defect or damage is found, immediate measures shall be taken (JSCE, 2001).

Maintenance and repair strategy should be developed effectively that fulfilled with the requirements of deterioration mechanism management. This management is conducted by collecting deterioration degree from each individual member into database, and performing initial inspection that normally with simple methods, such as hammer tapping and visual observation that covered the visual information data such as cracking, scaling, color change or stain, spalling, exposure, corrosion and rupture of steel reinforcement in concrete (Uomoto, 2003). Another method foras sisting the inspection like core drilled will gather an existing concrete condition, and investigate the internal defects, such as carbonation depth, chloride ion diffusion, cracking, void, and corrosion. By this method, relatively big device is required and became difficult to determine the number of inspection mark related with cost and work problems. In addition, there is a partial damage or danger to cut off a steel reinforcing bar in core drilling process.

To solve the problems, an alternative method such as narrow path drilled hole will be applied with small breaking test to inspect carbonation depth or chloride ion diffusion of internal structure members after several years, because it is not effective to conduct only one inspection item in one mark of measurement (Zacoeb, *et al*., 2007). This paper presents the basic principles of inspection technology that developed by using a stick scanner to capture concrete surface image from inspection borehole, whereas the assessment is confirmed by imaging analysis in photograph stage.

2. OUTLINE OF THE DEVICE

The device, namely as stick scanner that developed for capturing internal concrete surface image from small inspection borehole is shown in Figure-1 and the specification of device is shown in Table-1. The internal surface image is captured by inserting the stick scanner aperture mouth into inspection borehole and rotating in clockwise manual movement with one hand to capture all internal surface of inspection hole. The stick scanner is connected to a tablet PC through an USB port.

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ARPN Journal of Engineering and Applied Sciences

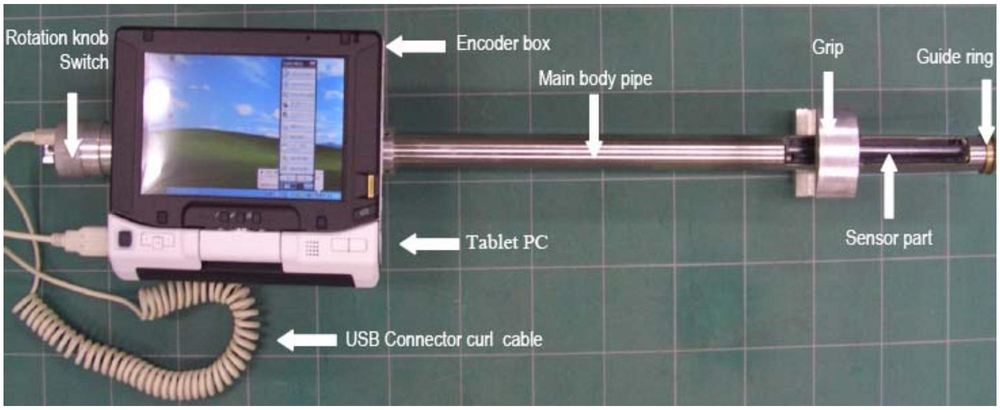

Figure-1. The stick scanner.

Table-1. Specification of stick scanner.

Main body	**Material** **Total length** **Insertion length** **Total mass**	**Stainless steel round pipe** **650mm** **350mm (extent up to 1000mm by installing the extension of steel pipe)** **1040gr (tablet PC excluded)**
Sensor	Type Length Reading size Resolution Focus depth	Contact Image Sensor (CIS) 120mm 105 x 356mm 600dpi (dot per inch) 1mm
Curl cable	Length	700mm (connector included)
Mobile Instrument	OS PC CPU Memory	Windows®/2000/ME/XP AT compatible machine equipped with USB port Pentium(R) - 266MHz or higher 64MB (minimum)

The structure of encoder as shown in Figure-2 consist of three major parts, such as encoder roller, circuit board and stainless steel pipe for inserting the sensor. The encoder is covered by steel box to protect the contents from dust, shake, and damage.

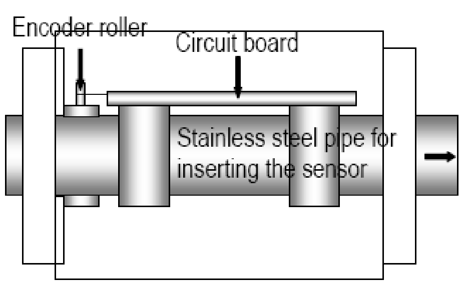

Figure-2. Encoder.

Sensor part as shown in Figure-3 is having a sensor length of 120mm and resolution of 600DPI. The stick scanner sensor has a CIS type with focus depth of 1mm. In order to keep the focus length, as the distances of surface inspection borehole with the scanning sensor are changeable, a pair of guide rings and scanner aperture mouth was established to support a stable rotational movement. The guide ring diameter is assumed to be 1mm smaller than inspection borehole diameter of 24.5mm. In addition, a pair of guide rings that installed had made the scanner possible to conduct a front and back movement. The stick scanner is enabled for capturing image of inspection borehole up to 350mm in depth.

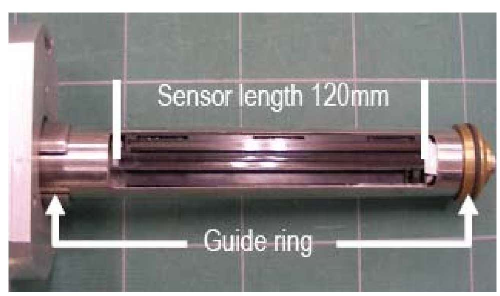

Figure-3. Sensor.

Although hand partial or supporter grip is a little hard to grab, it has a smooth configuration which curved so that a system could be supported enough on the examination object. Rotation knob part as shown in Figure-4 has a ruler and degree of rotation guide for confirming the insertion length and rotation direction of sensor. A rotation of sensor is manual and internal surface image capturing process can be conducted by pressing the start switch to run the scanner software that installed in tablet PC.

Figure-4. Rotation knob.

Cable part is using a curl code with USB port for connecting with tablet PC. By using this cable type, it is possible to conduct a scanning process continuously and avoid a problem from cutting by twist. Tablet PC that used in this experiment is FMV series with the weight of 580gr and display monitor size is 5.5". When image capturing is processed, the scanning image can be displayed and analyzed by touching monitor and can be rotated in any directions.

3. EXPERIMENTAL WORKS

3.1 Image size calibration

The accuracy of image reading representation is investigated by inserting a 1mm grid sheet as shown in Figure-5 into the aluminum stiff pipe of the same internal diameter as an inspection hole. The grid sheet right face is scanned with stick scanner, and a representation image is acquired as shown in Figure-6. The distance of each point of a rotation and axial direction was confirmed from the representation image, whereas the accuracy was compared with an actual measurement. In addition, with the sensor resolution of 600dpi, the grid sheet length was computed (actual measurement) per mm as 1 pixel is 0.042mm.

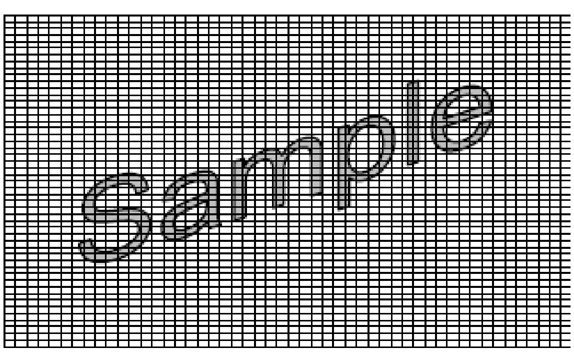

Figure-5. Grid sheet paper.

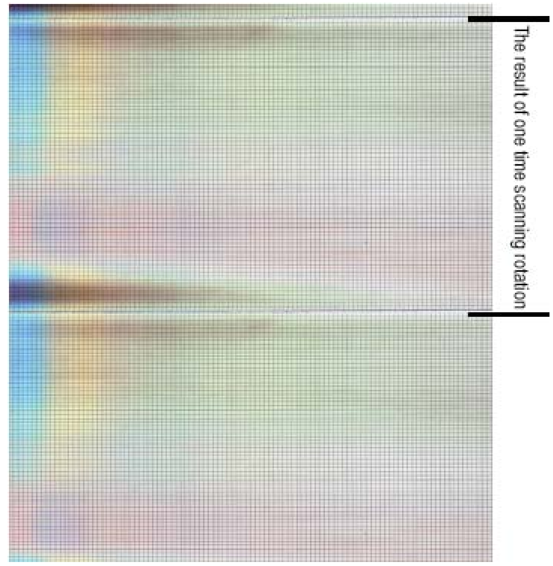

Figure-6. Representation of captured image.

3.2 Crack width verification

Accuracy of crack width measurement is examined by cutting a cylinder specimen with an inspection drilled hole into two equal parts as shown in Figure-7. Artificial crack is created by inserting a spacer block between two test specimens and supporting in fixed position as shown in Figure-8. The crack widths that had been analyzed were 0.05, 0.1, 0.2, 0.4, 0.5, 0.6, 0.8, 1.0, 1.5, 2.0, 3.0, 4.0, and 5.0mm. The calculation method of crack width was confirmed by counting the pixels number of cracking part from the representation image is shown in Figure-9.

Figure-7. Cylindrical specimens.

Figure-8. Artificial crack making.

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ARPN Journal of Engineering and Applied Sciences

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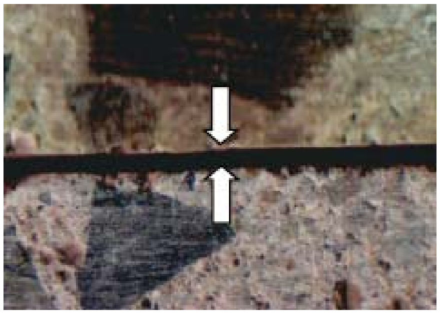

Figure-9. Cracking part image.

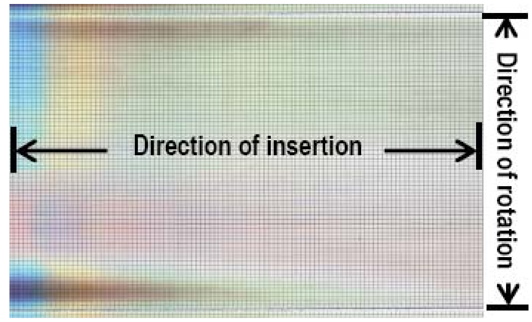

Figure-10. The acquisition image.

3.3 Image characteristic

Figure-10 shows the acquisition image for one scanning rotation. The result of measurement of the direction of insertion and rotation is shown in Table-2. From this table, the error measurement for insertion and rotation direction became 0.14 and 1.42%, respectively. This error is possible caused by the different of diameter between the rings made to rotate the roller of an encoder with the inspection hole, but this error does not pose any problem practically and still in the tolerance level.

Table-2. Image size measurement error.

Direction	Pixel number	Actual (mm)	Experimental (mm)	Error (%)
Insertion	2432	102	102.1	0.14
Rotation	1787	74	75.1	1.42

The crack width measurement is calculated from three times observation in three different parts of crack in the same image for each actual value. The result of crack width measurement is shown in Table-3 with mean error of absolute value of all the tolerances is 2.63%.

Table-3. Crack width measurement error.

Actual value (mm)	Pixel number			Experimental (mm)			Mean value (mm)	Mean error (%)
	1st	2nd	3rd	1st	2nd	3rd		
0.05	1.0	2.0	1.0	0.042	0.084	0.042	0.06	12.0
0.1	3.0	2.0	2.0	0.126	0.084	0.084	0.10	-2.0
0.2	5.0	5.0	4.0	0.210	0.210	0.168	0.20	-2.0
0.4	10.0	9.0	10.0	0.420	0.378	0.420	0.41	1.5
0.5	12.0	12.0	12.0	0.504	0.504	0.504	0.50	0.8
0.6	14.0	15.0	16.0	0.588	0.630	0.672	0.63	5.0
0.8	20.0	19.0	19.0	0.840	0.798	0.798	0.81	1.5
1.0	24.0	23.0	24.0	1.008	0.966	1.008	0.99	-0.6
1.5	36.0	36.0	36.0	1.512	1.512	1.512	1.51	0.8
2.0	49.0	50.0	50.0	2.058	2.100	2.100	2.09	4.3
3.0	72.0	73.0	73.0	3.024	3.066	3.066	3.05	1.7
4.0	97.0	97.0	95.0	4.074	4.074	3.990	4.05	1.2
5.0	120.0	122.0	118.0	5.040	5.124	4.956	5.04	0.8

The gap between object and the contact image sensor in this scanner is consistent in two dimensional (insertion and rotation direction). It means an image pixel always becomes the same size with scanner reading resolution. Scale calibration became unnecessary with this scanner, and the distance between two arbitrary points in image can be easily measured from the pixels number. The captured image from inspection borehole in maximum reading size of 105 x 356mm for one time scanning is contains more than 20Megapixels that can be obtained at maximum quality of 600dpi. This image is enabled to confirm fine aggregate or cracking condition bigger than 0.1mm.

This scanner can perform accumulation display of image as well as pixel size being constant precisely because there is no image distortion. If the insertion length is more than maximum reading size of sensor, it will require for extra image capturing process by inserted the

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sensor part deeper into inspection borehole. The common parts of image are shown in Figure-11 and both images are partially overlapping became one image on PC with composition method.

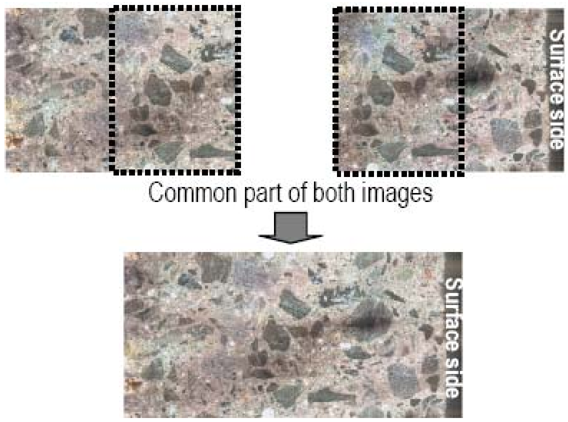

Figure-11. Composition method of image.

4. FIELD APPLICATION

Reinforcing bar investigation is performed in the first stage by a cover meter to determine a drilling location and avoid a reinforcing bar cutting accident. Investigation of internal defect such as cracking or void is possible by scanning image after having sprayed with phenolphthalein solution for carbonation depth measurement in dry or wet core drilling process. While for chloride ion diffusion, it must be performed in dry process and sprayed with nitrate silver solution ($AgNO_3$). The measurement is possible by calculating a number of pixels in the scanning image part with color changes after having sprayed with the solution. The scanning process is conducted after dry conditioning of inspection borehole. Inspection procedure with this scanner, from reinforcing bar investigation to the segment restoration for various investigations with this device is shown in Figure-12.

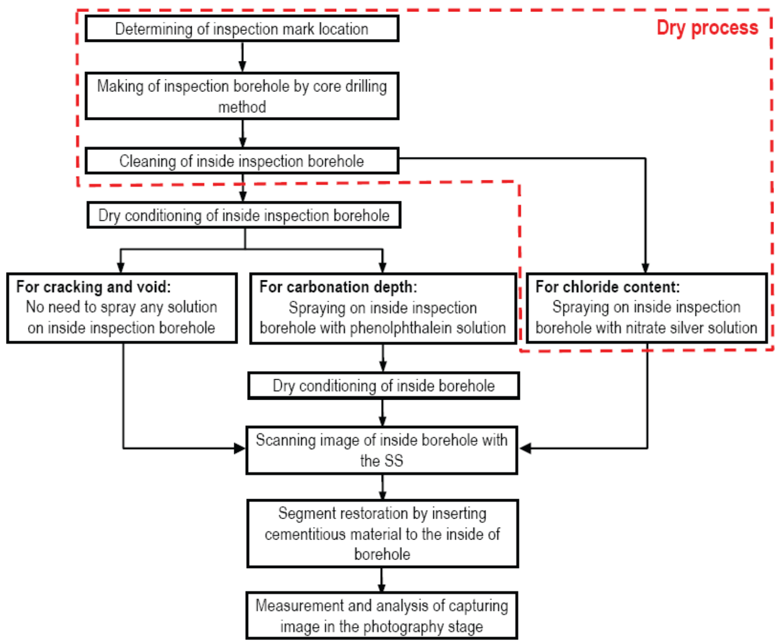

Figure-12. Flowchart of various inspections.

The measurement, such as crack width or carbonation depth that appeared in scanning image is confirmed easily by counting the number of pixels. This digital image characteristic is also enabled to conduct a various analyses. For scanning image sample result is shown in Figure-13 that contains information about internal concrete defects, such as carbonation depth, crack condition and alkali silica gel.

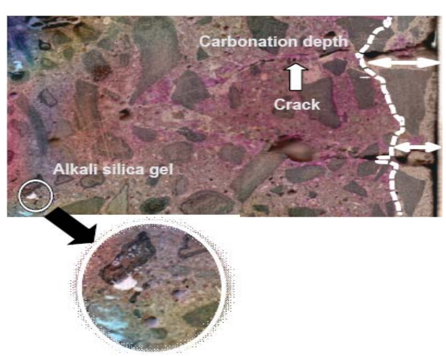

Figure-13. Sample of final image analysis.

5. CONCLUSIONS

Internal inspection of concrete structure that conducted by this stick scanner is effective to obtain plural information from one inspection mark. By using a small inspection borehole diameter of 24.5mm, it will faster for restoring concrete segment and giving no any significant effect towards structure performance. The capturing image with maximum quality more than 20Megapixels is enabling for analysis the condition of internal concrete that will be beneficial for assessing and determining the maintenance plan. Future research work will examine the applicability of this scanner for field investigation in other internal concrete structures deterioration.

ACKNOWLEDGEMENTS

This research work is part of the study that conducted by the first author during Doctor Course at Graduate School of Science and Engineering, Saga University. Sincerest thanks to the Ministry of Education, Culture, Sports, Science and Technology of Japan for financial support through the Monbukagakusho scholarship.

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