DEVELOPMENT of ADVANCED INSPECTION DEVICE for INSIDE CONCRETE STRUCTURES

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ABSTRACT: Increasing awareness in economic and social risk of aging, deterioration, extreme events on civil structure and infrastructure have been followed by recognizing the need of advanced structure soundness assessment methods and devices. Nowadays, these tasks are conducted by visual observation and traditional methods such as the tap testing. This paper describes one of visual inspection devices that developed with drilled hole for investigating inside concrete structure by scanning image analysis. The developed of stick scanner performance and procedure in series of inspections were informed too. The advantages of the stick scanner is making the possibility for effective and secure working with a good precision to obtain plural information from one inspection mark.

KEYWORDS: local destructive test, drilled hole, stick scanner, image analysis, plural information

INTRODUCTION

Concrete is the most common material used in construction world because of its workability, durability, and relatively low in cost. However, concrete dependent upon elapsed time same as with all materials will be deteriorated due to various reasons. Continuous concrete structure soundness assessment should provide data from the inside of structures for understanding various structural performances and predicting in the 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.

In general concrete structures are durable, usually requires a minimum of repair and maintenance. However, there is a situation when damage or defect call for remedial measures. Before conducting some remedial measures, it is important to identify the basic causes of damage or defect. Otherwise, an improper and ineffective repair technique may be selected for this case. This situation is almost same as medical treatment in sickness.

One of the remedial measures to a technical judgment of the symptoms and modes of deterioration is visual inspection that assessing the structures by visual observation, sometimes with another method assists, and conducted in once a month, once a year, or once in several years, according to the need of inspection after the construction finished. In some cases, sound inspection is conducted by hammering in order to assess the soundness of concrete quality. The periodic inspection covered the visual information data such as cracking, scaling, color change or stain, spalling, exposure, corrosion and rupture of steel reinforcement inside concrete.

Maintenance method and repair plan are pushed forward depending on cheap development and effective inspection technology that required by deterioration mechanism management. This

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management is conducted by collecting deterioration degree from each individual member into database, and performing initial inspection that normally with simple methods, such as visual observation and hammer tapping. Another method for assisting the inspection like core drilled will gather an existing concrete condition, and investigate the inside 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 inside structure members after several years, but it is not effective to conduct only one inspection item in one mark of measurement.

In consideration of the above mentioned reasons, an advanced technology that effective, economical, and secure is developed to obtain plural information that required for selecting a maintenance method and repair plan from one inspection mark. This inspection technology is developed by using a special scanner (stick scanner) to capture concrete image from inside drilled hole, whereas the measurement is confirmed by imaging analysis in photograph stage. In this paper, the structure and performance of stick scanner in application examples were informed.

2. OUTLINE OF STICK SCANNER

The stick scanner for capturing inside concrete image from drilled hole is shown in **Figure 1** and the specification of device is shown in **Table 1**. The inside image is captured by inserting the stick scanner aperture mouth in drilled hole. The stick scanner is connected to a computer through a serial port. It is easy to make the stick scanner a manual rotation movement inside drilled hole with one hand to capture all inside surface of drilled hole.

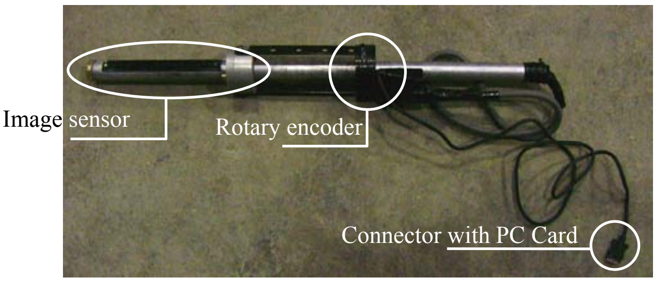
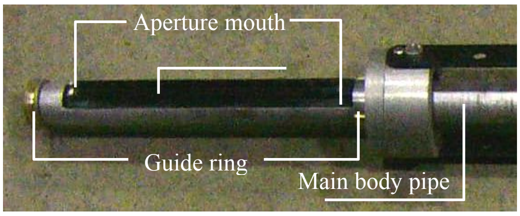


Figure 1. The stick scanner

Table 1. Specification of stick scanner

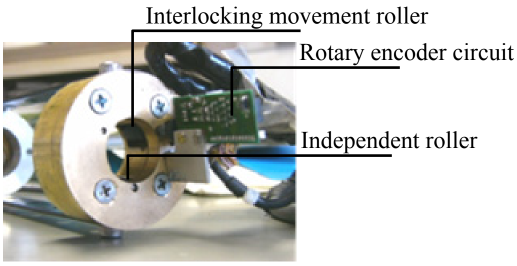
Sensor	Type Length Reading size Resolution Focus depth	: Contact Image Sensor (CIS) : 120mm : 105 x 356mm : 300dpi (dot per inch) : 1mm
Cable	Length	: 766mm (connector included)
Mobile Instrument	OS Interface CPU Memory	: Windows®/2000/ME/XP : Type II Serial Port : 100MHz or higher : 128MB (minimum)

The image reading principle is similar with general handy scanner that measured movement distance of image sensor by a rotary encoder, and then read line data of image by image sensor as two dimensions image. 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 inside drilled hole with the scanning sensor are changeable, a pair of guide rings and scanner aperture mouth was established to support a stable rotational movement. Detail of image capturer and guide ring is shown in **Figure 2(a)**. The guide ring diameter is assumed 1mm smaller than inside drilled hole with the diameter of 24.5mm.



a. Detail of image capturer

b. Rotationally Movement direction (clock wise)



c. Detail of Encoder

Figure 2. The image capturer

The high quality image can be captured by fixed focusing an object of inside drilled hole with this scanner sensor. The movement roller which interlocking a main body pipe and rotary encoder circuit is being stable as interlocking movement roller as shown in **Figure 2(c)**, and for movement distance data reading from encoder part is enabled to be confirmed without release it. In addition, a pair of guide rings that installed in encoder part and aperture mouth had made the scanner is possible to conduct a front and back movement. The stick scanner is enabled for capturing image of inside drilled hole up to 250mm in depth.

3. INSPECTION PROCEDURE

In the first stage, a reinforcing bar investigation is performed by steel bar detector to determine a drilling location. Inspection procedure with this scanner, from reinforcing bar investigation to the segment restoration, is shown in **Figure 3**. The actual scanning operation is shown in **Figure 4**, and the stick scanner will turn on manually by hand operation. The image of inside concrete drilled hole is displayed on notebook PC monitor by real time.

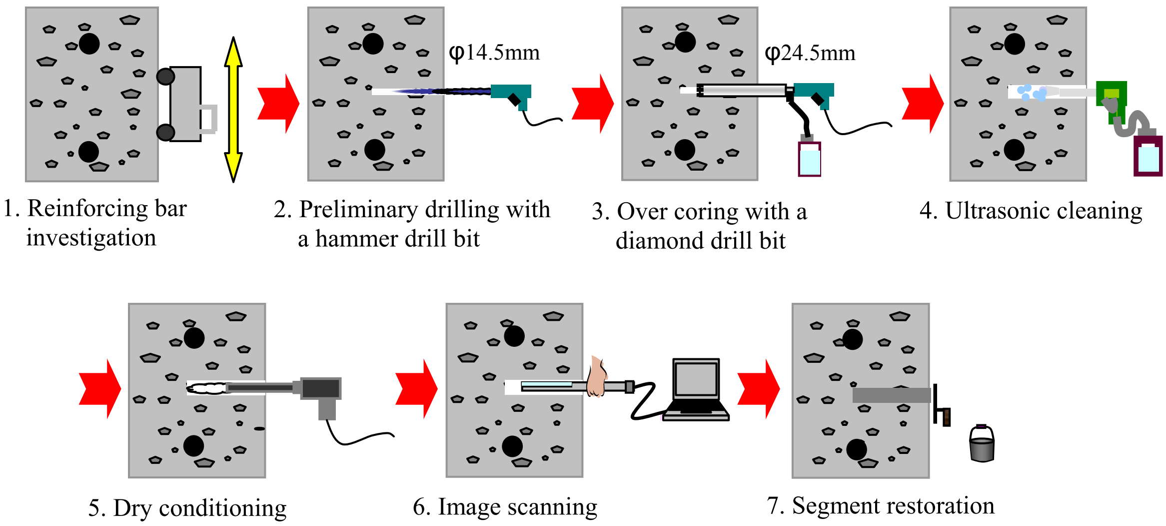


Figure 3. Inspection procedure

Figure 4. Scanning operation

For the core drilled method, a preliminary hole with the diameter of 14.5mm was drilled by hammering drill bit, and next to hole with the diameter of 24.5mm was over cored by the diamond drill bit that installed a guide stick as shown in **Figure 5**. The purpose of preliminary hole is to make up for the deficit of current reinforcing bar investigation limit. The accuracy of this investigation more than 100mm of depth is low, so that guide stick with diameter of 13mm will be able to confirm the existence of steel reinforcing bar before over coring. The diamond drill bit using in this method will improve the accuracy of circle and straightness of drilled hole. There are many preliminary processes in this method, but on the other hand there are many advantages too, such as the working time reduction (about 30 minutes), the damage degree minimization, and no danger to cut off steel reinforcing bar comparing with conventional coring method.

Figure 5. Diamond drill bit

Investigation of inside defect such as cracking or void is possible by scanning image after having sprayed with phenolphthalein solution for carbonation depth measurement with coring and cleaning can be performed in wet processes. While for chloride ion diffusion, they must be performed in dry processes and sprayed with nitrate silver solution ($AgNO_3$). The measurement is possible by confirming the scanning image part with color changes after having sprayed with the solution. Flow chart of various investigations with this scanner is shown in **Figure 6**.

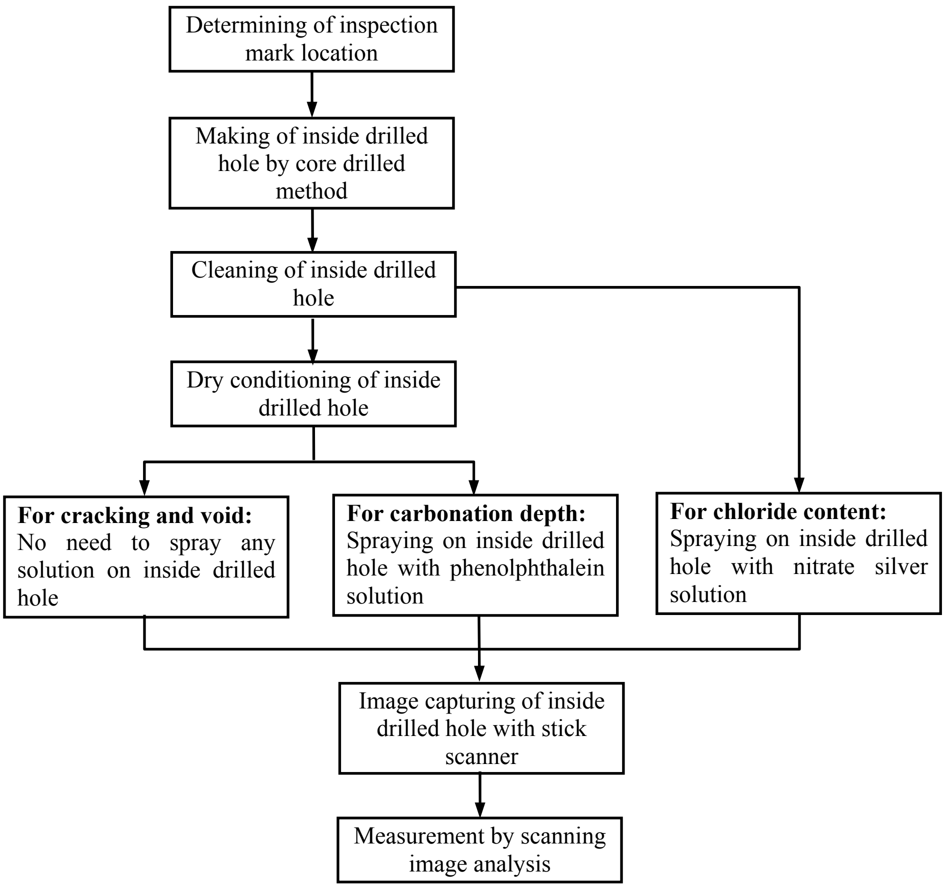


Figure 6. Flow chart of various investigations

4. CHARACTERISTIC OF SCANNING IMAGE

Distance from object to the contact image sensor in this scanner is one dimensional in consistency. It means an image pixel always becomes the same size with scanner reading resolution. One pixel in image becomes 84.7µm for reading resolution setting of 300dpi. It is verified with theoretical value as affixed scale as shown in **Figure 7** for confirming the scanning image. Scale calibration by various measurements with digital camera became unnecessary with this scanner, and the distance between two arbitrary points in image can be easily measured from the pixels number.

Figure 7. Scanning image confirmation

The captured image from inside drilled hole in maximum reading size of 105mm for one scanning is contains more than 1,200,000 pixels that can be obtained by one scanning at maximum quality. This image is enabled to confirm fine aggregate or cracking condition lower than 0.5mm. This scanner can perform accumulation display of image as well as pixel size being constant precisely because there is no image distortion. If the scanning depth greater than maximum reading size, it will require for extra scanning by inserted the image capturer deeper. The image common parts are shown in **Figure 8** and both images are partially lapped over in one image on PC with composition method. This method usually is performed by viewing, so the image error about 0.5% in axial direction occurs.

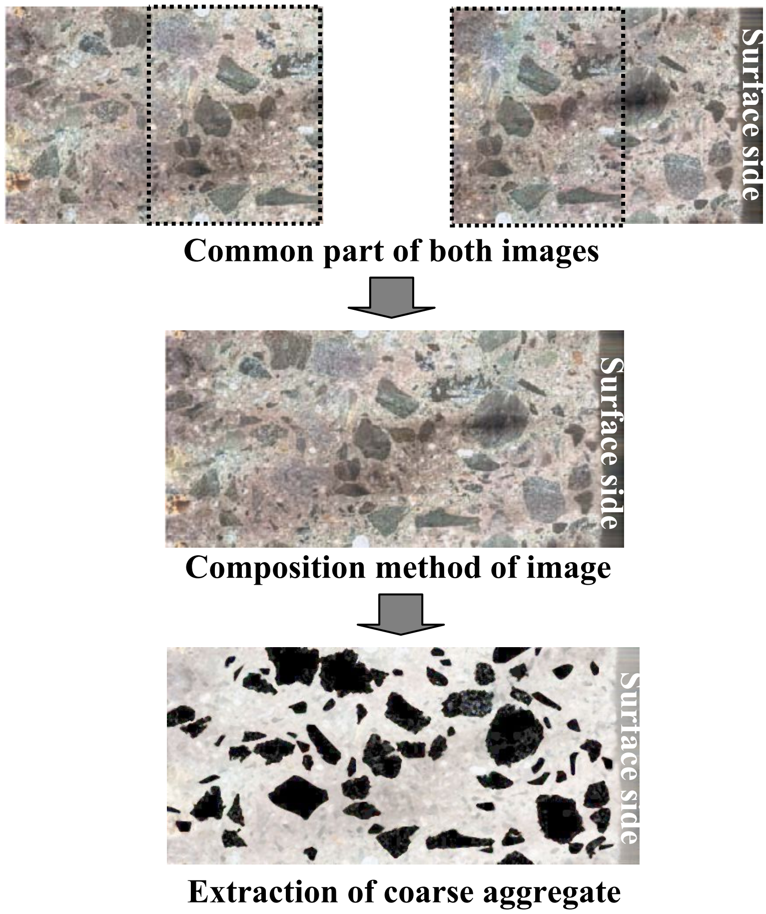


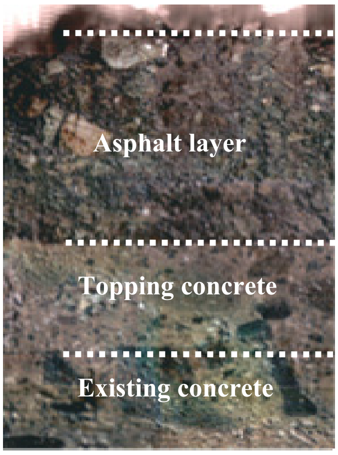
Figure 8. Image processing

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 example, extraction of coarse aggregate (aggregate more than 5mm in size) by image processing is enabled to calculate the rate of coarse aggregate area and homogeneity of concrete. In other words, it is possible to evaluate the segregation degree in concrete from scanning image.

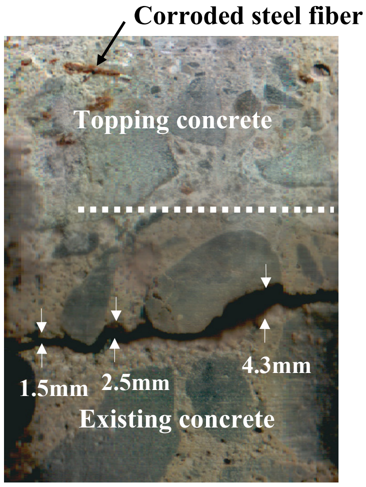
5. APPLICATION EXAMPLES

a. RC slab investigation

Many old RC slabs of expressway were overlaid by steel fiber reinforced concrete in the top surface of slab to extend the service life. However, fatigue life of RC slab for the most part is limited, concerning of connectivity between existing and topping concrete in the case that surface treatment of existing concrete during construction is not performed properly and repetitive load subjected intensively. **Figure 9a** is example of cracking investigation for RC slab that overlaid with steel fiber reinforced concrete and asphalt. This scanning image shows an inside drilled hole that cored from the asphalt layer surface to the existing concrete layer. There was no disconnection between existing with topping concrete construction and no cracking occurs. Whereas **Figure 9b** is similar construction method examples for another RC slab. For this slab, topping concrete color was clearly different from the existing, and there was no disconnection. The stability crack width from 1.5 to 4.3 mm was observed in existing concrete region under around 10mm from surface of existing concrete. In addition, by using conventional core method in such investigation, core specimen will be broke on cracking side or crack width is not possible to measure exactly.



a. Version 1

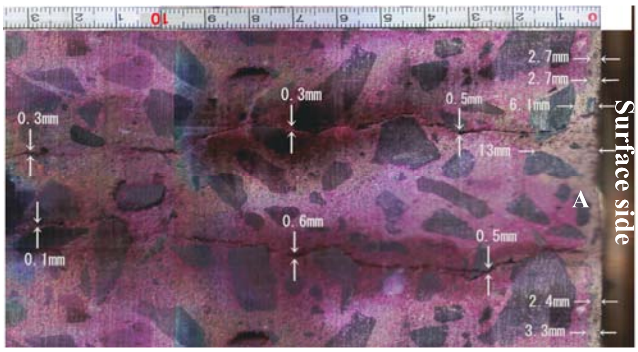


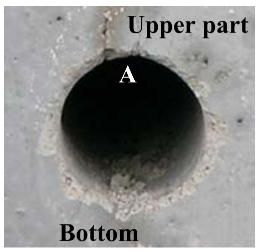
b. Version 2

Figure 9. Bridge slab inside image

b. RC pier investigation

For RC pier strengthening against earthquake, concrete jacketing method has been adopted. In this method, temperature cracking occurs due to the confinement of existing concrete and sunk reinforcing bar. For durability diagnosis, inside cracking and carbonation depth were investigated. **Figure 10** shows inside cracking widths and carbonation depths that measured from original scanning image. Development of inside cracking is in axial vertical direction, while inside cracking for the depth more than 130mm is confirmed. The carbonation depth is different depending on distance from crack. The maximum carbonation depth occurs in cracking side with value of 13mm and 5 times deeper than in isolated position where carbonation depth is around 2.5mm. For evaluating of service life from carbonation depth, it has to measure not only in sound but also in defect part.





The front of drilled hole

Figure 10. Inside cracking and carbonation image

6. CONCLUSION

Inspection by the stick scanner using drilled hole has many advantages to compare with conventional core method. This scanner makes the possibility for effective and secure working with a good precision to obtain plural information from one inspection mark. Future research work will examine the applicability of this scanner for investigating other inside concrete structures deterioration, such as ASR and frost damage.