Development and Applications of a Total Station with a Built-in Crack Scale

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ABSTRACT

Cracking is one of the most important features to identify the current condition states of concrete structures. Structural engineers can analyze the cracking patterns and its extension over a period of time to make proper decisions on structural repair and/or rehabilitation. In this research, a crack detection system called “KUMONOS”, which is a total station equipped with a built-in crack scale is described. The system generates a crack map with higher accuracy without reaching the structure within arm length, providing safer working environment to the inspector compared to the traditional close-up visual inspection method. Furthermore, the data obtained by KUMONOS can be integrated into the data from a 3D laser scanner or photogrammetry. The crack widths determined by the built-in crack scale varies depending on his/her experience and prejudice, causing certain amount of dispersion in the determination of crack widths. In order to minimize this dispersion, a methodology was developed to calibrate the human eye by providing a short training course. This paper describes the theory of crack measurement using KUMONOS system, calibration training program, and some examples of the combined usage of KUMONOS with photogrammetry and a 3D laser scanner.

INTRODUCTION

Recently deterioration of infrastructures has been a serious problem in Japan. Over 50% of about 160,000 bridges with the length of more than 15 meters will have its service life of more than 50 years in about 20 years (The

Japanese Ministry of Land, Infrastructure, Transport and Tourism, 2011). It is anticipated that more and more budget will be required for maintenance and rehabilitation of aging infrastructures. In order to extend the service life of the structure, there is an urgent need to make a strategic maintenance plan and prioritize the repair/rehabilitation projects based on better information obtained by routine inspection process.

The benefit of preventive maintenance strategy is widely recognized in many countries including Japan, the United States. The preventive maintenance strategy is effective to extend the service life of the structures by applying proactive actions based on the prediction of the future condition and obviate critical deteriorations and damages, enabling it to prevent the excessive concentration of structural maintenance or renewal in the same period of time, and to conduct the proper maintenance utilizing limited budget and human resource. As the approach of preventive maintenance requires accurate deterioration prediction, it is crucial to obtain accurate and quantitative measurement data of current condition.

Cracking is one of the most important information obtained during routine inspections of concrete structures. Cracks occur as the results of various deteriorations and damages of concrete (Concrete Foundations Association of North America). It is possible to perceive and predict the structural condition by analyzing the cracking length, widths and patterns.

Traditionally, crack inspections have been executed manually using a crack width ruler during the close-up inspection from a lifting cage, snooper trucks or scaffolds (Figure 1). Detected cracks were manually sketched for inspection record. This approach requires additional cost for approaching the cracks and closing a lane to set up the snooper trucks. In that sense, inspectors are often exposed to the traffic during the lane closure, and to the falling hazard while working in high places. Moreover, making records relying on hand-written sketches does not allow sufficient accuracy, or accurately monitoring changes over time.

Even though a technology has been developed to automatically detect cracks out of the digital photographic images (Fujita et al., 2006), it has technical problems that it is difficult to properly distinguish cracks from dirt and shadow on the wall and to accurately measure the width of cracks.

The “KUMONOS” is a total station equipped with a built-in crack scale. “KUMONOS” has the crack scale on the reticle of its total station, enabling inspectors to accurately measure cracks without approaching close to the structure. “KUMONOS” provides inspections that ensure higher accuracy and safer environment, and better cost-benefit performance compared to the conventional close-up visual inspections.

Figure 1. Traditional crack measurement from a lifting cage.

FEATURES OF "KUMONOS"

"KUMONOS" is a crack inspection system, consisting of a total station which is equipped with a built-in crack scale and a proprietary software (Figure 2). It has the function to determine the widths, shapes and lengths of cracks, and to automatically draw a crack distribution map using a 3D CAD software (Nakaniwa et al., 2008).

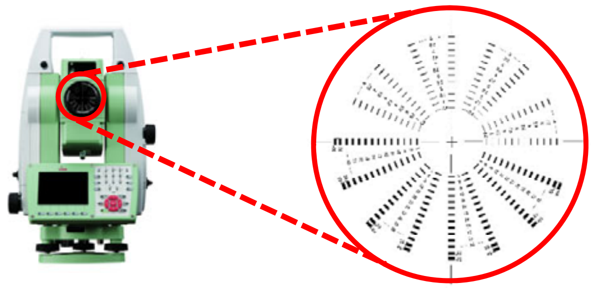

Figure 2. "KUMONOS", a total station equipped with a crack scale.

The crack scale installed in KUMONOS has scale marks radially allocated. The marks in the upper half are numbered from 0.5 through 6 in 0.5 increment, and those in the lower half are from 7 through 18 in 1 increment between the marks according to their width. The radially allocated marks with the same width overcome the issue that the reticle cannot be rotated, and enable it to measure cracks with different angles. As depicted in Figure 3, an inspector overlap the marks with the targeted crack, finds the scale mark that matches the targeted crack width, and input the scale number into the system to determine the target crack width. Then "KUMONOS" software calculates the crack width from the relation of the input scale number and the distance to the target. Table 1 lists the minimum measurable widths using "KUMONOS" in terms of the distances to the target. The crack width looks different depending on the angle of viewing the crack. That is, the appearance of crack width is determined by the direction of the crack and the tilt of the surface. As an inspector has to measure cracks from a fixed location during the on-site crack inspection, it is not always possible for the inspector to take a measurement from the right angle. In order to solve this problem, the proprietary software in KUMONOS can convert the measured crack widths depending on the angle and distance to the targeted crack, and provides the 'corrected' crack widths.

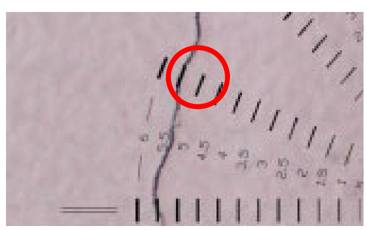

Figure 3. Collimation through "KUMONOS".

Table 1. Minimum measurable crack widths in terms of distance.

Distance(m)	1.5	10	20	30	40	45	60	80	100
Width(mm)	0.007	0.144	0.088	0.132	0.177	0.199	0.265	0.353	0.441

"KUMONOS" can measure the shapes of cracks with positional coordinates by measuring the starting and ending points, and prominent points on a crack. This enables crack shapes to be accurately recorded.

KUMONOS proprietary software can easily export the collected crack data and the crack map is plotted out into a figure on a 3D CAD software. This is because the data of measured points which contains positional coordinates are automatically connected with lines, which reduces man-hours to draw figures.

COMPARISON WITH TRADITIONAL METHODS

Using "KUMONOS", inspectors can measure the width of cracks from a distance without approaching the structure, which provides inspections that ensures the safety of inspectors and high cost/benefit performance. Inspectors can easily measure cracks using this system in unreachable places as shown in Figure 4.

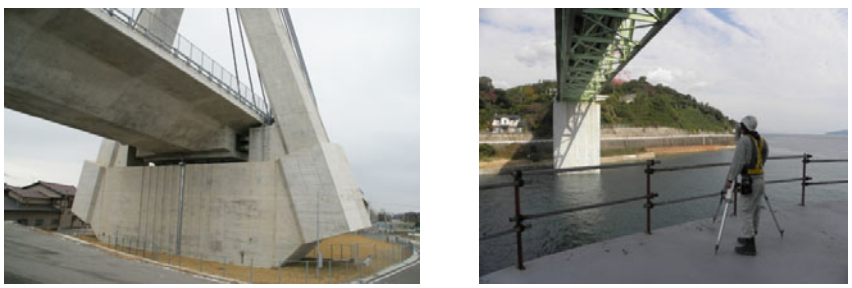

Figure 4. Measurements of a bridge pier using "KUMONOS".

The accuracy of the conventional approach and the method using "KUMONOS" were compared in the measurements of locations and shapes of cracks. Each of the three inspectors made drawings of the simulated cracks which were on an A3-size panel hung up 50 meters away. One drawing was made using the conventional approach; visual observation using a pair of binocular and manual sketch. The other drawing was made using the method using "KUMONOS". Each drawing was overlaid on the simulated cracks to compare its accuracy. While the errors of 28 to 46 mm in the measurement of locations and shapes were observed in the conventional approach, KUMONOS allowed only 1 to 3 mm difference. The accuracy of crack location mapping was dramatically improved compared to the hand-written sketch because the data of the locations and shapes of cracks is saved as the data of positional coordinates.

Accurate measurements of the location and shapes of cracks enable us to accumulate historical inspection data and monitor the changes over time by comparing the data. The crack extension is important information to predict the future condition of the structures. Figure 5 shows a part of drawings of the same area of a bridge which is located in Yamaguchi prefecture. The left drawing is from the measurement taken in the first year, and the right one is in the second year. They show, for example, the crack numbered 1 in the left drawing extended from 200 mm long and 0.1 mm wide in the first year to 340 mm long and 0.25 mm wide in the second year. Also, it becomes clear that the crack numbered 2 is a newly occurred crack. The result enables us to predict the future conditions of the structural surface.

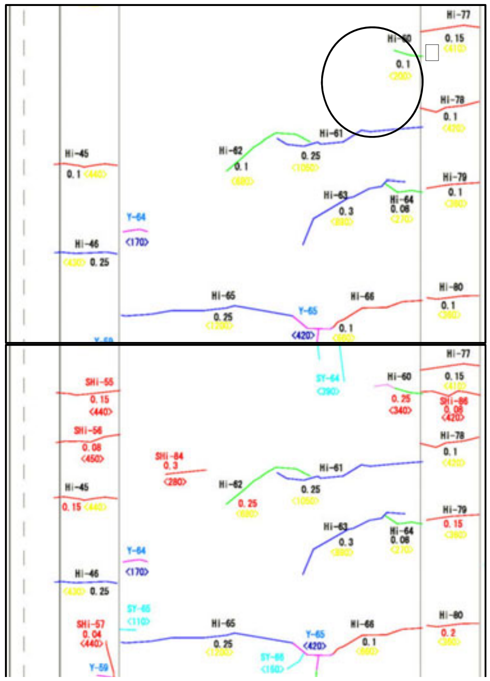

Figure 5. Comparison of the results of measurements taken in the first year (the left) and in the second year (the right).

The cost performance of the conventional approach and the new approach were also compared. When a measurement was conducted in the 4800 square meters of an investigation area of a bridge shown in Figure 4, the costs for a field work was saved by 430,400 JPY (equivalent to about 34% off) in total, including the rental fee for a boom lift and the labor cost for a flag person to control the traffic, and man-hours for office work to create drawings were reduced from 14 days to 7 days in the new approach.

FURTHER TECHNICAL DEVELOPMENT

1. Combined use with digital photography

Even using “KUMONOS”, it is not easy to detect and record fine alligator cracks with high frequency. Therefore, a method was developed, in which “KUMONOS” is used with digital photographic images to reduce cost and labor for such cases. In this method, inspectors first record the shape of cracks by photographing, and then measure only the widths of cracks using “KUMONOS” as shown in Figure 6. As the cracks are visually checked through “KUMONOS”, the probability of missing the cracks is reduced when the data of cracks is automatically extracted from the data of the digital images. Also, when measuring the locations and shapes of cracks, the accuracy can be improved by measuring the structures’ outline and joints using “KUMONOS”, and correcting the digital photographic images based on the data.

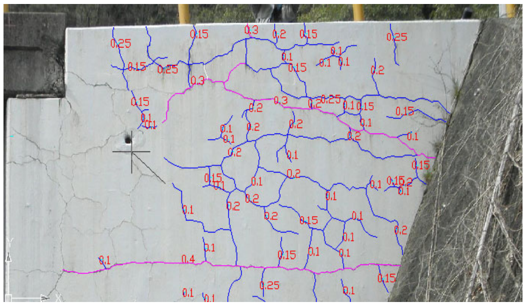

Figure 6. A composite view of the data of cracks from KUMONOS and digital photography.

2. Combined use with a 3D laser scanner

The data collected using "KUMONOS" can be composite with the point cloud data collected using a 3D laser scanner. It is difficult to reproduce cracks on complicated structures such as slope blocks and shotcrete walls in 2D. However, deficiencies on such structures can be visualized by overlapping them with the shapes measured using a 3D laser scanner.

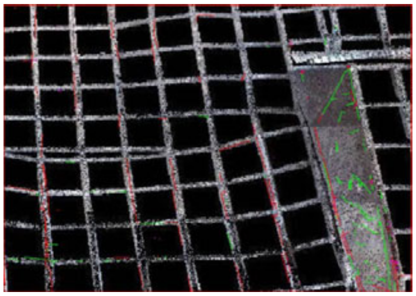

Figure 7. A composite view of cracks and point-cloud data.

CRACK WIDTH CALIBRATION

It is necessary to choose the scale mark of "KUMONOS" which matches with the targeted crack width. The measurement accuracy depends greatly on which scale marks is chosen by the inspector in the field. A proving test was conducted to calibrate the accuracy of crack width detection.

1. Calibration Method

The 10 lines of 'known' widths (Table 2) were prepared as simulated cracks on a wall. 28 participants measured the width of each line using a crack scale and "KUMONOS". The lines numbered 1 through 5 lie widthwise, and the lines numbered 6 through 10 lie longwise, and the wall with the simulated cracks were 7.5m away from "KUMONOS". Each participant performed a measurement using manual crack scale and "KUMONOS", and received about 30 minutes of 'calibration training' between the first and second KUMONOS measurements, according to his/her tendency in choosing the scale marks. During the 'calibration training', the different simulated cracks were used from those used in the calibration test. An instructor guided the trainees to the correct value in order to correct his/her tendency in reading built-in scale marks.

Table 2. The widths of the simulated cracks.

Line number	1	2	3	4	5	6	7	8	9	10
Width (mm)	0.16	0.56	0.48	0.24	0.40	0.20	0.54	0.38	0.14	0.46

2. Calibration Result

Table 3 shows the mean value of the errors which were observed in the first and the second measurement by the 28 participants. Table 3 leads a conclusion that measurements can be more accurate using "KUMONOS" than using a conventional crack scale. Moreover, it is clear that the technical 'calibration training' improved the crack width detection accuracy from the comparison of the results of the first and second "KUMONOS" measurements.

Table 3. Errors which were observed in the measurements.

Used tool/equipment	Average error
Crack scale (mm)	0.07
KUMONOS, 1st time (mm)	0.05
KUMONOS, 2nd time (mm)	0.03

Table 4 indicates the numbers and the widths of simulated cracks, and the mean values of the measurement results. The table suggests the tendency that people read the thinner scale than the actual crack width. It is considered to be because the crack is covered with the scale mark when the crack is thinner than the scale mark, which makes it difficult to compare the width of cracks and scale marks. However, this calibration test proves that this tendency can be corrected by a technical calibration training.

Table 4. Mean value in measurements using a crack scale and "KUMONOS".

Line number	1	2	3	4	5	6	7	8	9	10
Thickness of the line(mm)	0.16	0.56	0.48	0.24	0.40	0.20	0.54	0.38	0.14	0.46
Crack scale(mm)	0.12	0.52	0.43	0.19	0.35	0.17	0.48	0.30	0.09	0.37
KUMONOS 1st time (mm)	0.13	0.51	0.41	0.21	0.35	0.19	0.48	0.35	0.11	0.44
KUMONOS 2nd time (mm)	0.15	0.51	0.45	0.24	0.39	0.19	0.50	0.36	0.13	0.44

CONCLUSIONS

In this research, a system to measure cracks of structures, named "KUMONOS" was described, which is a total station equipped with a built-in crack scale. Further technical development combining the system with digital image processing is also described. This research proves that cracks can be accurately measured from a distance using this system. Additionally, this system enables us to measure cracks which could not be measured using the conventional method. Also, "KUMONOS" provides the measurements with a better cost/benefit performance and safety, eliminating the need for equipment such as man lift and snooper trucks. Moreover, cracks can be efficiently measured using “KUMONOS” with digital photography, and easily visualized with a 3D laser scanner.

Also, the accuracy calibration training proved that;

- Measurement using “KUMONOS” can be made more accurately than using crack scales.
- A technical calibration training corrects the tendency of inspectors in measurement, eventually improves measurement accuracy by minimizing the dispersion.

More historical data records need to be accumulated to establish a method to take measurements more accurately. The continuity of the effect of calibration training also needs to be verified.

It is expected that accumulating accurate data using this system provides the owner of the structure with information to make a better decision on repair and rehabilitation.

ACKNOWLEDGMENT

We would like to thank Mr. Hirotaka Hayashi and Ms. Ikue Okano from Kansai Construction Survey Co., Ltd. for the data acquisition and English translation for this paper.

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