DEVELOPMENT AND ON SITE APPLICATION OF INSPECTION SYSTEM USING LIGHT WAVE CAMERA WITH BUILT-IN CRACK SCALE

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Abstract: This study presents a high speed and precise inspection system that allows remote measurement of cracks using a light wave camera with built-in crack scale. Its applicability is shown with a long and large bridge in Aomori Prefecture which leads Japan in bridge asset management.

Through this study, not only have such technical issues as the hazard and time limitations in constructing temporary footholds been provided fundamental resolutions but also timely production of crack measurements, coordinate conversions and transformation into CAD drawings have become possible, to create a unique crack measurement and 3D database management system.

Keywords : Light wave, Crack width, Remote, 3D CAD

Normally crack and deformation inspections are necessary before planning repair and maintenance works for bridges, tunnel linings and other construction structures. In Japan, a conventional method, close visual inspection, is normally used for inspecting cracks of concrete infrastructures. In the conventional method, temporary footholds must be constructed or a man-lift truck must be used for inspecting cracks of high rise bridges or tunnel crowns. This causes injury risks of inspectors, more working duration and more overall inspection cost. Moreover, the close visual inspection cannot be performed at some parts of structures at high place.

From these reasons, it is necessary to develop a long distance inspection method that can add inspection data such as crack shape, length and width on CAD drawings simply and automatically. The newly developed method makes possible precise inspection of the deterioration of structures, and tracking the changes in structures in the long term.

In this paper, the development and three demonstration tests for proving the preciseness, accuracy and reliability of the newly developed system are described.

In Japan, the close visual inspection method is widely used as described in RTRI 2007¹. In this conventional method, an inspector observes cracks on concrete surface visually. Normally, the inspector uses a chalk to mark crack positions and uses a crack scale to compare and evaluate crack width. After taking photos of cracks, crack details such as crack position, shape, length, width, and inspection date are recorded in a sketch book on site. Finally, the inspection data is written down on CAD drawings manually. The problems of this conventional method are as follows:
1) The accuracy of inspection results greatly depends on the experiences of each inspector.
2) Human errors occur easily in inspecting, sketching processes.
3) Difficult to observe and evaluate small cracks.
4) Necessary to construct temporary footholds or to use a man-lift truck for inspecting cracks at high places.
5) Require a great deal of time for drawing the crack information on CAD drawings.
6) Difficult to investigate crack progressing.
7) Require a great deal of time for updating the inspection data in the long term.

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The new crack inspection system was developed by combining a non-prism type light wave distance-measuring system with a crack scale. The non-prism type light wave is used for measuring a distance up to long-distance range. The built-in crack scale is used for evaluating crack width.

The normal focal scope of a light-wave survey camera is shown in Fig.1. The newly developed focal scope with a built-in crack scale is shown in Fig.2. The crack scale was created in the shape of a spider’s web that is easy to compare and match a crack direction by rotating the crack scale.

Fig.3 shows the newly developed survey camera, a light-wave camera with built-in crack scale. This new survey camera has the following features:

1) A built-in crack scale

The spider’s web shape crack scale is attached on a focal scope as shown in Fig.2. The light wave distance survey camera with built-in crack scale can be used to observe the crack in a long distance. An inspector can choose the most suitable number on a crack gauge by rotating the focal scope and comparing the crack gauge with a crack observed through the camera. Then the crack width can be calculated from a crack gauge number, a distance and an angle between the camera and the crack.

2) A 40-time zoom telescope lens

Normally, a light wave survey camera uses a 30-time zoom lens. In this case, in order to improve the observation efficiency of the built-in crack scale for observing cracks from a long distance, a 40-time zoom lens is used. By using a high magnification lens with built-in crack scale, this new camera can be used to inspect crack width and three dimensional coordinates of cracks from a long distance effectively and accuracy.

Based on the test results, this new camera has the capacity to detect 0.3 mm width cracks in a range of 39 m, and 0.1 mm width cracks in a range of 12 m. Hence, it is not necessary to use footholds or a man-lift truck to inspect the cracks at high places.

3) A non-prism type light wave measuring function

The invented camera has a high efficiency to measure the distance in a long distance by using a light wave measuring system with a non-prism type without using a reflection prism and seal. In good environmental conditions, the non-prism type light wave measuring function can measure a distance up to 350 m.

4) A collimation angle correction measuring

The measured size and width of an object depend on the measured distance and angle. The actual crack width can be measured perpendicular to a crack and a structure surface. In the case of measuring angularly, the measured crack width changes depend on the measure angle. Three dimensional coordinates of cracks are calculated from the distance, the angle between the survey camera and observed cracks. By combining the crack width obtained from the built-in crack scale, and the three dimensional coordinates of the crack, the collimation angle correction is performed automatically to calculate the actual crack width.

5) Camera application software

Four application programs were also developed for processing and transforming the measured data to be digital data and CAD drawings. An inspector can use these developed programs on a personal computer link with CAD software, to create a three dimensional view, plan view, elevation view and unfolded view automatically and easily. The time required for post processing and drawing works can be reduced remarkably by using these developed programs.

a) Automatic connecting line program

The automatic connecting line program is used for
connecting the start, end and broken points of crack lines. An angle correction is also performed at the same time of connecting line. A crack shape can be recorded exactly and precisely by using this program.

b) Specific planer projection and unfolded curve surface program

The specific planer projection program is applied for processing crack data at a slope or a wall surface. In the case of a bridge pier and a tunnel lining, the unfolded curve surface program is applied for processing the measured data.

c) High speed drawing program

The measured data can link with any CAD software on the market. By using the high speed drawing program together with CAD software, a deformation view, a plan view, an elevation view and an unfolded view with crack shape of the observed surface can be drawn easily and in a short time.

d) Data exchange program

The data exchange program is used to exchange digital measured data with other types such as 3D laser scanner data, GIS data and National Spatial Data Infrastructure (NSDI). Hence, it is possible to combine measured data with other types of data to perform a three dimensional analysis of observed structures.

5. TEST RESULTS AND DISCUSSION

In this session the results of three demonstration tests carried out for investigating the scattering of measured results caused by human factor, the minimum measurable crack width and the maximum measurable distance and the preciseness of angular measurement, are shown and described.

a) Test objectives

In a crack inspection operation, an inspector observes a crack through a camera and selects the most suitable crack gauge number from a built-in crack scale. After that, the crack width is calculated automatically from the selected crack gauge number and the measured distance. Hence, the selection of a gauge number by the inspector has the most effect on the measured results. Here, demonstration tests for investigating the scattering of measured results caused by human factor (inspector) were carried out.

b) Test method

As shown in Fig.4, a wall with an imitation crack was made and placed outdoor, then the developed camera was set at the same height and perpendicular to the imitation crack. The operation of selecting the gauge number is shown in Fig.5. By rotating the built-in crack scale and comparing an observed crack with a crack gauge, the gauge number of the crack gauge that has the same size as the observed crack is selected and recorded. After this manual operation, the crack width is calculated automatically.

c) Test conditions

The test conditions are shown in Table.1. This test was carried out by 100 surveyors who have experiences in surveying varying from a few years to expert and licensed surveyor. The real crack width of the imitation crack is measured by a microscope.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (m)</td>
<td>10, 20, 30, 40, 50</td>
</tr>
<tr>
<td>Crack width (mm)</td>
<td>0.1, 0.2, 0.3, 0.4, 0.5</td>
</tr>
<tr>
<td>Place</td>
<td>Outdoor</td>
</tr>
<tr>
<td>Object</td>
<td>Imitation crack which has a uniform crack width</td>
</tr>
<tr>
<td>Date at time</td>
<td>9:00~17:30, 3 days in the first week of June (summer)</td>
</tr>
<tr>
<td>Acceptable error</td>
<td>All errors are not more than 0.05 mm</td>
</tr>
</tbody>
</table>
d) Test results

The test results of the measure distance of 20 m, the measured crack width and its number of results are shown in Fig.6~10. Fig.6 shows that there are some measured data that have errors more than 0.05 mm in the case of 0.1 mm crack width. While for the wider crack, all measured data have an error of less than 0.05 mm. Based on the test criteria, the minimum measurable crack width for measure distance 20 m is 0.2 mm.

The minimum measurable crack widths for each measure distance are summarized in Table.2. These results show that the minimum measurable crack width depends on the measure distance. The measurable crack is wider when the measure distance is shorter.

In Japan, normal requirement of crack inspection for road tunnels is 0.2 mm, for telecommunication tunnels is 0.3 mm, and for bridges is 0.3 mm (ref. RTRI 2000 2) etc.). These results show that the maximum measurable distance for 0.2 m cracks is 27 m, and for 0.3 mm cracks is 39 m. Hence it is possible to set the camera on a pavement or a tunnel invert for inspecting the crack at tunnel crown without using any foothold or man-lift truck. It is also possible to inspect from a long distance up to 27~39 m.

b) Test method

Fig.12 shows an outline of the tests of angular measurement. The camera was set at the same height and at the angular range of 30°~80° to an imitation crack. Firstly, both ends of crack were measured and then a reference point on the wall was measured. The coordinates of the three points were used to define a surface and correct the crack width automatically by the collimation correction program. Finally the measured results were compared with the real crack width that was measured by a microscope.

c) Test conditions

The test conditions are shown in Table.4. This test was carried out by 100 surveyors. The imitation crack widths are 0.1 and 0.2 mm, and the measure angle are 30°, 40°, 50°, 60°, 70° and 80°.

d) Test results

Test results of the measure distance of 20 m, camera angle of 30°, 60°, and 80° of both 0.1 and 0.2 mm crack are shown in Fig.13~18. The range of errors and the maximum absolute error of the measured results are summarized in Tables.5~6. These results show that all measured results from the angular camera have an error of less than 0.05 mm. Thus it can be concluded that the crack width can also be measured precisely in the case of angular measurement in the range of 30°~80° by using the included collimation correction function.

Here we will show as an example of this crack inspection system used for crack width measurement of reinforced concrete structure with the case of Aomori Chuo Ohashi.

This is a long and large bridge under the jurisdiction of Aomori prefecture. It is located in the middle of Aomori City, crossing over the Japan Railways Tohoku Main Line Aomori Switchyard. 582 m long, 4-lane, it is in use since 1986.

In order to inspect the cracks in the piers, by the conventional method there would have been need to construct many large scale footholds on the Aomori Switchyard premise. However, by the newly developed method, such footholds are unnecessary, giving no trouble to the JR trains. It is also much more safe and economical; moreover in addition to crack drawings, drawing using 3D...
**Fig.6**  Test results of crack width 0.1 mm, distance 20 m

**Fig.7**  Test results of crack width 0.2 mm, distance 20 m

**Fig.8**  Test result of crack width 0.3 mm, distance 20 m

**Fig.9**  Test result of crack width 0.4 mm, distance 20 m

**Fig.10**  Test results of crack width 0.5 mm, distance 20 m

**Table 2**  Minimum measurable crack width

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Min. crack width (mm)</th>
<th>Maximum error (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.1</td>
<td>0.05</td>
</tr>
<tr>
<td>20</td>
<td>0.2</td>
<td>0.05</td>
</tr>
<tr>
<td>30</td>
<td>0.3</td>
<td>0.05</td>
</tr>
<tr>
<td>40</td>
<td>0.4</td>
<td>0.05</td>
</tr>
<tr>
<td>50</td>
<td>0.4</td>
<td>0.05</td>
</tr>
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</table>
Fig. 11 Relation between the minimum measurable crack width and the measure distance

Table 3 Maximum measurable distance

<table>
<thead>
<tr>
<th>Crack width (m)</th>
<th>Max. measurable distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>12</td>
</tr>
<tr>
<td>0.2</td>
<td>27</td>
</tr>
<tr>
<td>0.3</td>
<td>39</td>
</tr>
</tbody>
</table>

Fig. 12 Diagram of the angular measurement test

Table 4 Conditions of the angular measurement test

<table>
<thead>
<tr>
<th>Subject</th>
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<tbody>
<tr>
<td>Distance (m)</td>
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<tr>
<td>Crack width (mm)</td>
<td>0.1, 0.2</td>
</tr>
<tr>
<td>Object</td>
<td>Imitation crack which has a uniform crack width</td>
</tr>
<tr>
<td>Measure angle</td>
<td>30°, 40°, 50°, 60°, 70°, 80°</td>
</tr>
<tr>
<td>Time and date</td>
<td>9:00~17:30, 3 days in the first week of June (summer)</td>
</tr>
<tr>
<td>Acceptable error</td>
<td>All errors are not more than 0.05 mm</td>
</tr>
</tbody>
</table>

Fig. 13 Test result of camera angle 30°, crack width 0.1 mm

<table>
<thead>
<tr>
<th>Measured crack width ± error (mm)</th>
<th>Number of results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean: 0.12 mm, standard deviation: 0.03 mm</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 14 Test result of camera angle 60°, crack width 0.1 mm

<table>
<thead>
<tr>
<th>Measured crack width ± error (mm)</th>
<th>Number of results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean: 0.11 mm, standard deviation: 0.02 mm</td>
<td></td>
</tr>
</tbody>
</table>
Test results of 0.1 mm wide crack

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Range of error (mm)</th>
<th>Max absolute error (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>-0.02 to +0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>20</td>
<td>-0.02 to +0.03</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Measured crack width ± error (mm)
(mean: 0.13 mm, standard deviation: 0.03 mm)

Test results of 0.2 mm wide crack

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Range of error (mm)</th>
<th>Max absolute error (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>-0.04 to +0.01</td>
<td>0.04</td>
</tr>
<tr>
<td>20</td>
<td>-0.04 to +0.01</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Measured crack width ± error (mm)
(mean: 0.19 mm, standard deviation: 0.02 mm)

Measured crack width ± error (mm)
(mean: 0.19 mm, standard deviation: 0.03 mm)

Measured crack width ± error (mm)
(mean: 0.22 mm, standard deviation: 0.02 mm)
laser scanner could be made.

Fig.19 shows how the crack measurements were made. Both 3D laser scanner and the developed camera keep data in coordinates, so if the conditions are the same they can be overlapped to show both data in one drawing (Fig.20). From this, plan view etc. of crack drawings (Fig.21) can be drawn out. Without using footholds, the inspection works of cracks could be carried out to the required precision safely and economically in 4 days.

In this paper, the development and the features of the new crack inspection systems using a light wave survey camera with built-in crack scale is described. Then the demonstration tests results for investigating the scattering due to human factor in the case of perpendicular and angular measurement are shown. The results proved that the crack width obtained from both cases using this inspection system is precise and accurate enough in practice. Moreover, the tests of the maximum measurable distance show that, this developed camera can be used for measuring cracks from a long distance effectively.

This crack inspection system was applied for inspecting the cracks at the 582 m-long, 4-lane pier bridge in Aomori prefecture, Japan. The inspection works completed safely and economically in 4 days. In this application, the three dimensional cracks information were drawn together with structure drawings by CAD software and saved digitally.

From the applications on site, the following features of this newly developed inspection systems have been proved:

1) Capable to inspect from a long distance and at high places.
2) Easy to create digital CAD drawings.
3) Capable to investigate the progress of cracks.

Now, the developed inspection systems are being used in many sites of many environments in Japan. New features such as automatic image processing and automatic tracking systems are under development. The effective utilization of the observed crack information for maintaining concrete structures in the long term is also under investigation.

References