

Invention of crack inspection system using a light wave survey camera with a built-in crack scale

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ABSTRACT: In this paper, the newly developed crack inspection system using a light-wave with a built-in crack scale is proposed. This inspection system is more precise and higher speed than a conventional crack inspection method. The demonstration tests for proving the preciseness of this system in the case of perpendicular and nonperpendicular measurement are described. Moreover, the minimum measurable crack width and the maximum measurable distance are determined and tested. By using this newly developed crack inspection system, it is not necessary to construct temporary footholds for observing cracks at high place. Thus the injury risk of inspectors and inspection work duration can be reduced significantly. This inspection system can automatically transform the observed crack data into three dimensional digital data and link with CAD software, to create the unique 3D database crack management system. This has received the JSCE (Japan Society of Civil Engineers) Innovative Technique Award 2008.

1 INTRODUCTION

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. 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 the long distance inspection method that can add the inspection data such as crack shape, length, width on CAD drawings simply and automatically. The newly developed method should be possible to use for inspecting the deterioration of structures precisely, and tracking the changes of structures in long term.

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

2 CONVENTIONAL CRACK INSPECTION METHOD

In Japan, the close visual inspection method is widely used as described in RTRI (2007). In this conventional method, an inspector observes cracks on concrete surface visually. Normally, an inspector uses a chalk to mark crack positions and uses a crack scale to compare and evaluate a 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 using 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) Requiring a great deal of time for drawing the crack information on CAD drawings.
- 6) Difficult to investigate crack progressing.
- 7) Requiring a great deal of time for updating the inspection data in the long term.

3 DEVELOPED CRACK INSPECTION SYSTEM

3.1 Development background

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 a crack width.

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



Figure 1. Normal focal scope.

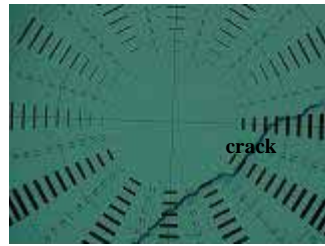


Figure 2. Newly developed focal scope.

3.2 Features of the developed crack inspection system

Figure 3 shows the newly developed survey camera, light-wave survey camera with a built-in crack scale. This new survey camera has the features as follows.

1) A built-in crack scale

The spider's web shape crack scale is attached on a focal scope as shown in Figure 2. The light wave distance survey camera with a 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 a camera and a crack.

2) A 40-time zoom telescope lens

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

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



Figure 3. The developed light-wave survey camera with a built-in crack scale.

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 the 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 the distance up to 350 m.

4) A collimation angle correction measuring

The measured size and width of an object depend on 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 and the angle between the survey camera and observed cracks. By combining the crack width obtained from a 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, 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 the 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, National Spatial Data Infrastructure (NSDI). Hence, it is possible to combine measured data with other types of data for performing the three dimensional analysis of observed structures

4 DEMONSTRATION TESTS

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.

4.1 Tests of scattering caused by human factor

1) Test objectives

In the 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 gauge number and the measured distance. Hence, the selection of a gauge number by an inspector has the most effect on measured results. Thus the demonstration tests for investigating the scattering of measured results caused by human factor or an inspector were carried out.

2) Test method

As shown in Figure 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 a an imitation crack. The operation of selecting the gauge number is shown in Figure 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.

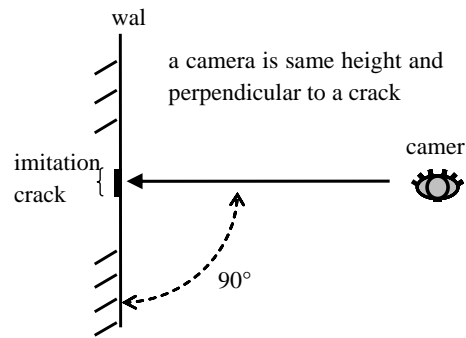


Figure 4. Outline of the scattering test.

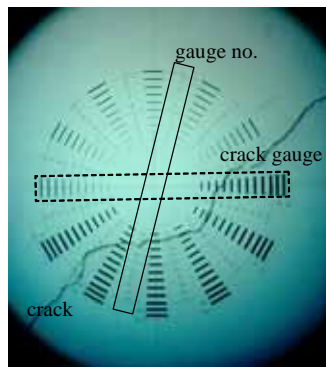


Figure 5. Comparing an imitation crack with a crack gauge.

3) 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 few years to expert and licensed surveyor. The real crack width of the imitation crack is measured by a microscope.

Table 1. Conditions of the scattering test

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

4) Test results

The test results of the measure distance of 20 m, the measured crack width and its number of results are shown in Figure 6~10. Figure 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 has an error less than 0.05 mm. Based on the test criteria, the minimum measurable crack width for measure distance 20 m is 0.2 mm.

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

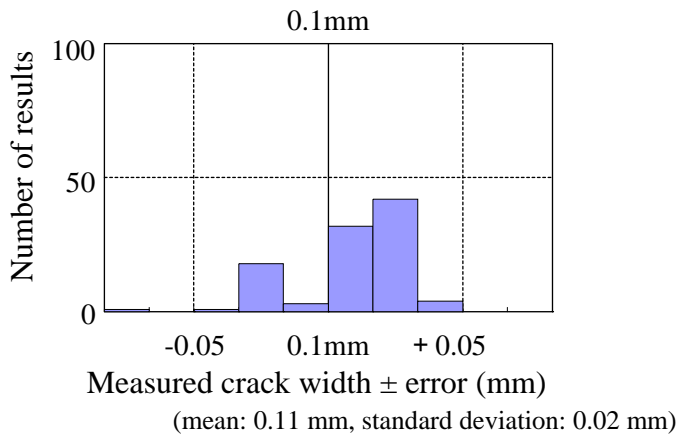


Figure 6. Test results of crack width 0.1 mm, distance 20 m.

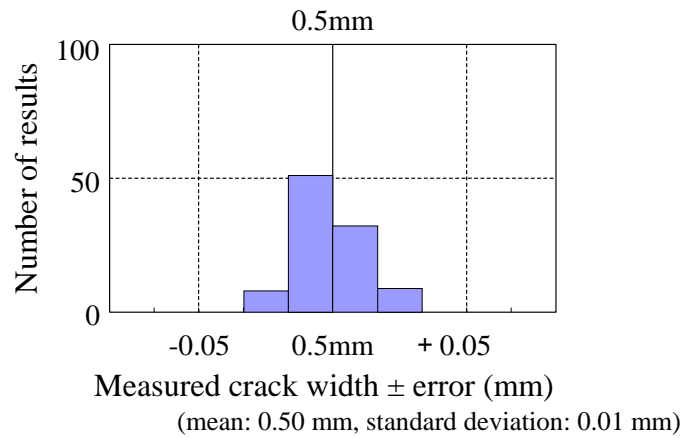


Figure 10. Test results of crack width 0.5 mm, distance 20 m.

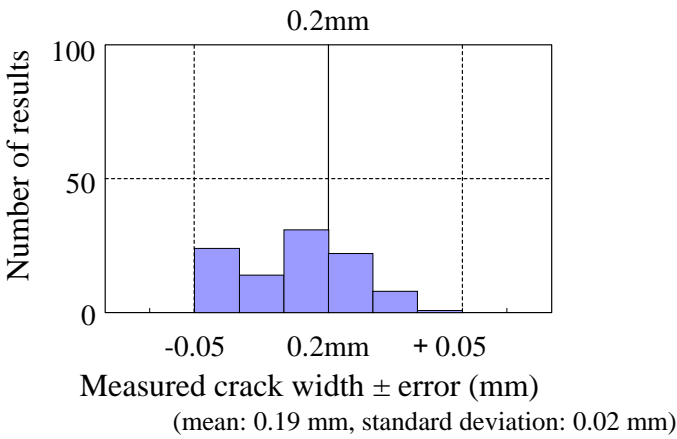


Figure 7. Test results of crack width 0.2 mm, distance 20 m.

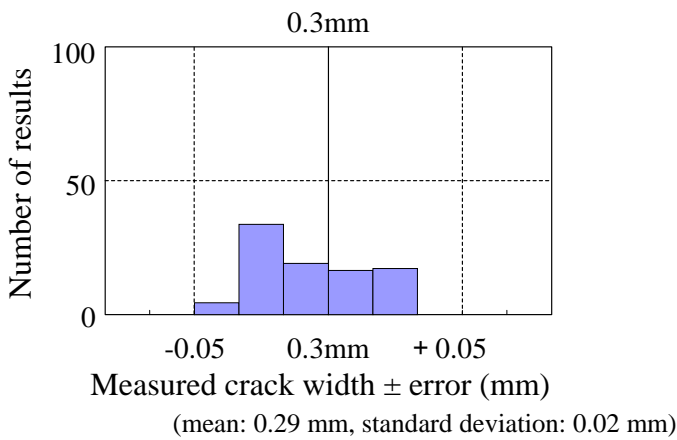


Figure 8. Test result of crack width 0.3 mm, distance 20 m.

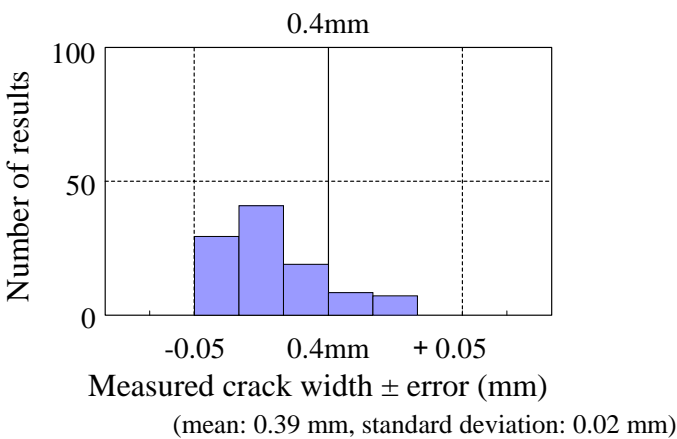


Figure 9. Test result of crack width 0.4 mm, distance 20 m.

Table 2. Minimum measurable crack width.

Distance (m)	Min. crack width (mm)	Maximum error (mm)
10	0.1	0.05
20	0.2	0.05
30	0.3	0.05
40	0.4	0.05
50	0.4	0.05

4.2 Tests of minimum measurable crack width and maximum measurable distance

In order to determine the minimum measurable and the maximum measurable distance, the same test procedures as described in the previous session were carried out. The tests were carried out at the distance of 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50 m. The measurable crack width is defined as the measured result that has an error within 0.05 mm.

The relation between the minimum measurable crack width and the measurement distance is shown in Figure 11.

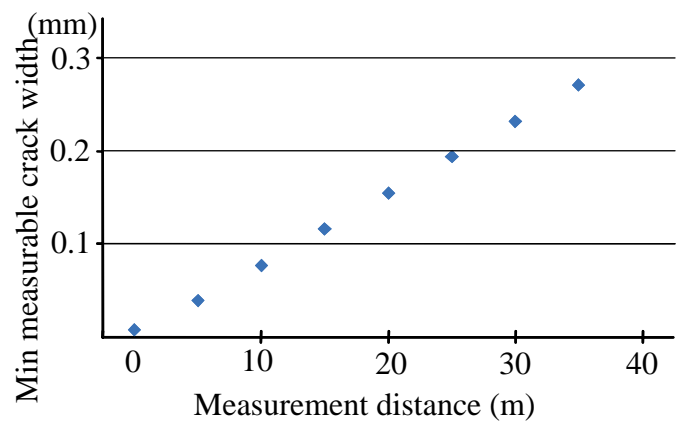


Figure 11. Relation between the minimum measurable crack width and the measure distance.

Table 3. Maximum measurable distance

Crack width (m)	Max. measurable distance (m)
0.1	12
0.2	27
0.3	39

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 etc.). These results show that the maximum measurable distance for 0.2 m cracks is 27 m, and for a 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 a lift-man truck. It is also possible to inspect in the long distance up to 27~39 m.

4.3 Tests of angular measurement

1) Test objectives

The precision of perpendicular measurement is demonstrated and proved in the previous two sessions. In usual inspection works, the measurement cannot be performed perpendicular to a target wall due to nearby obstacles. Theoretically, the measured crack width from an angular measurement is smaller than a perpendicular measurement. Thus, the collimation correction of an angular measurement should be performed for obtaining an actual width.

The automatic collimation function is included in this developed camera. In this session the tests for demonstrating the precision of this function is described. From past experiences of many surveyors, an angular measurement less than 30° causes too large error and unreliable results. Thus in this test, the range of a camera angle was set as 30°~80°.

2) Test method

Figure 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 three points are 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 measured by a microscope.

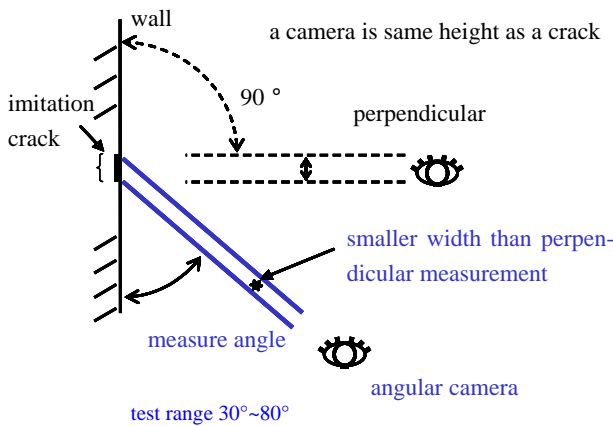


Figure 12. Outline of the angular measurement test.

3) Test conditions

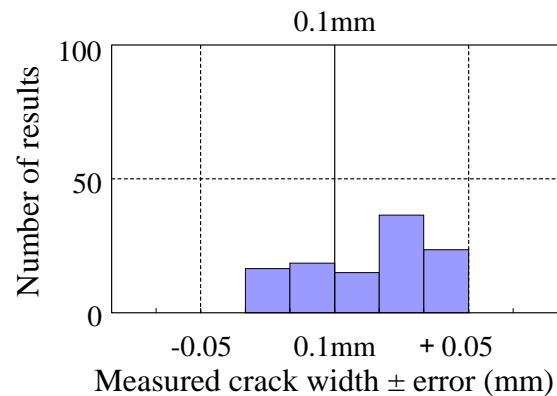
The test conditions are shown in Table 4. This test was carried out by 100 surveyors. The imitation crack widths are 0.1 and 0.2 mm, and the measure angle are 30°, 40°, 50°, 60°, 70° and 80°.

Table 4. Conditions of the angular measurement test.

Subject	Condition
Distance (m)	10, 20
Crack width (mm)	0.1, 0.2
Object	Imitation crack which has a uniform crack width
Measure angle	30°, 40°, 50°, 60°, 70°, 80°
Date at time	9:00~17:30, 3 days in the first week of June (summer)
Acceptable error	All errors are not more than 0.05 mm

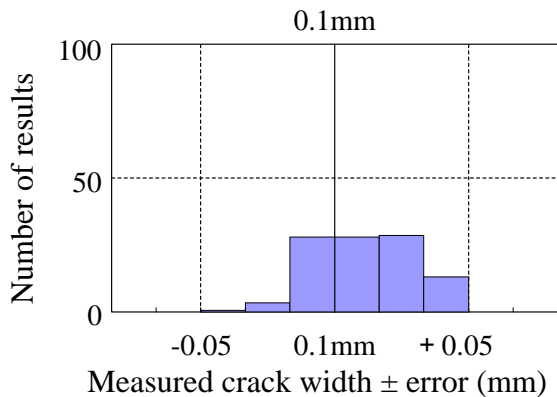
4) Test results

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 Figure 13~18. The range of errors and the maximum absolute error of the measured results are summarized in Table 5~6. This results show that all measured results from the angular camera has an error 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.



(mean: 0.12 mm, standard deviation: 0.03 mm)

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



(mean: 0.11 mm, standard deviation: 0.02 mm)

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

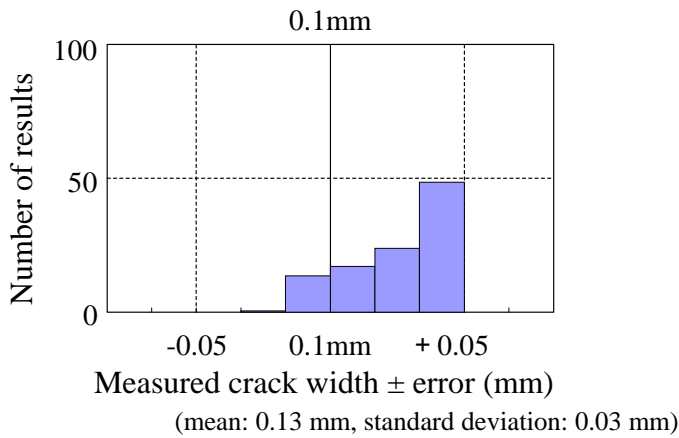


Figure 15. Result of camera angle 80°, crack width 0.1 mm.

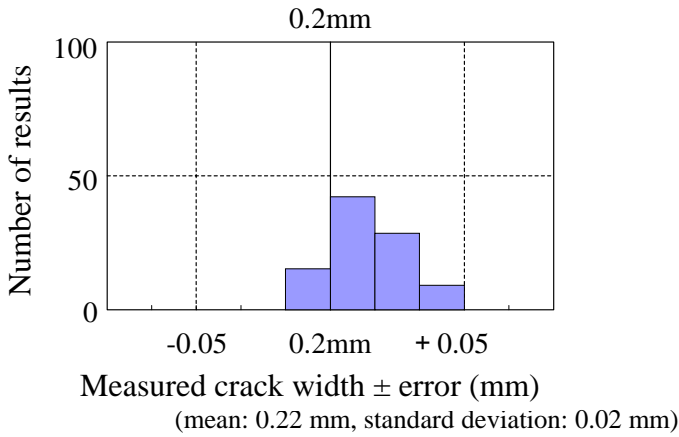


Figure 16. Result of camera angle 30°, crack width 0.2 mm.

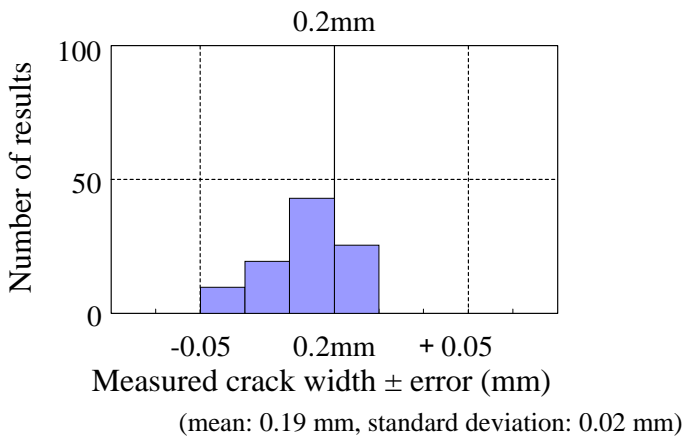


Figure 17. Result of camera angle 60°, crack width 0.2 mm.

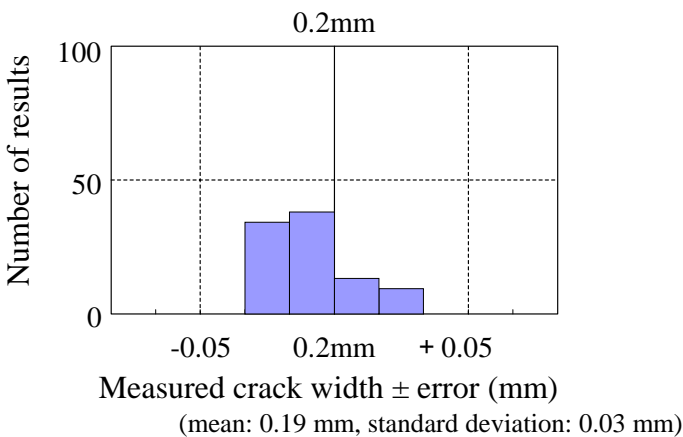


Figure 18. Result of camera angle 80°, crack width 0.1 mm.

Table 5. Test results of the 0.1 mm wide crack

Distance (m)	Range of error (mm)	Max absolute error (mm)
10	-0.02~+0.02	0.02
20	-0.02~+0.03	0.03

Table 6. Test results of the 0.2 mm wide crack

Distance (m)	Range of error (mm)	Max absolute error (mm)
10	-0.04~+0.01	0.04
20	-0.04~+0.01	0.04

5 SUMMARY

In this paper, the development and the features of the new crack inspection systems using a light wave survey camera with a 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 practical. Moreover, the tests of the maximum measurable distance show that, this developed camera can be used for measuring the crack in the 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 at the long distance and the high place.
- (2) Easy to create the digital CAD drawings.
- (3) Capable to investigate the progressive of cracks.
- (4) Capable to inspect only the newly occurring cracks.

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

REFERENCE

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- Railway Technical Research Institute (RTRI) 2007. *Maintenance Standards for Railway Structures and Commentary*: 102-104. Tokyo: Maruzen. (in Japanese)