Robotic Inspection Tests of Tunnel Lining Concrete with Crack Light-section Device on Variable Guide Frame

Daisuke Inoue[a], Takao Ueno[a], Satoru Nakamura[a]

[a]Institute of Technology, Tokyu Construction Co., Ltd.
E-mail: daisuke.inoue at tokyu-cnst dot co dot jp

Abstract –

There are approximately 10,000 road tunnels in Japan. Human visual inspections of the tunnels must be conducted once every five years. However, presently, the number of inspection engineers is insufficient and the cost incurred for the inspection is significantly high. In conventional crack inspection methods based on an image processing, inspection engineers process many images off site. However, these methods require a lot of effort to identify the cracks and dirt manually.

We have studied a brand-new robotic inspection method to measure the crack positions automatically by using high-resolution texture/depth images that are acquired based on the light-section method. In this report, we present the study outline and introduce the devices developed. Furthermore, we present the inspection results of tunnel lining concretes by using our method in contrast with both an actual road tunnel made by the conventional piling method and a simulated actual-size tunnel we made by the NATM method.

Keywords –

Tunnel inspection; Crack detection; Depth-image

1 Introduction

The Japanese government decided to periodically inspection the road tunnel once every five years since 2014. In principle, the inspection should be performed by near visual inspection to the tunnel overall length. The results of the inspection and diagnosis were recorded and saved, and a decision was made to classify the diagnostic results of soundness on a unified basis. Against such a background, issues such as a shortage of engineers and lack of budget to inspect road tunnels are becoming apparent [1].

Close visual inspection of a road tunnel is conducted by inspection experts, who observes the surface of the lining concrete in the vicinity using an aerial work platform or the like. The experts measured and recorded the degree of the changes in the cracks, floats, steps, efflorescence, honeycombs, water leakage and the like. The representative method to support the experts is based on an image processing [2]. Often, the method requires off-line image process for a large amount of image data of the concrete lining surface. Because the common method of the image processing recognizes dark pixels with cord-like arrange as the cracks, a dirt or the like can be erroneously detected as a crack. Various methods have been made to prevent these false detections, but some challenges still remain for completely automatic crack detection.

In order to solve these problems, the automatic crack inspection device based on the light-section method have proposed and developed to support close visual inspection [3]. The device is the one of the component of our robot system shown in Figure 1, called “Variable guide frame vehicle” developed for traffic-free tunnel inspection [4]. In this paper, we describe an outline of the device, and the results of the performance validation experiments of the device in contrast with both an actual road tunnel made by the conventional piling method and a simulated actual-size tunnel we made by the NATM method.

2 Mobile Light-section Device Developed

The authors have made it possible to distinguish between cracks and dirt by obtaining depth images as a three-dimensional shape of the concrete surface. In various methods to acquire the three-dimensional shape, a light-section method was adopted considering both the high resolution with 0.1 millimeter/pixel order and the portability for wide area inspection over kilometer order.

The light-section method acquires a three-dimensional shape by causing the slit-light and the area camera to move relative to an object for scanning, while maintaining a certain angle. It is based on the property that the slit-light deforms accordingly. By using the slit-light of a white LED, a color image (visible image) whose coordinates are coincident with the three-dimensional information can be obtained.

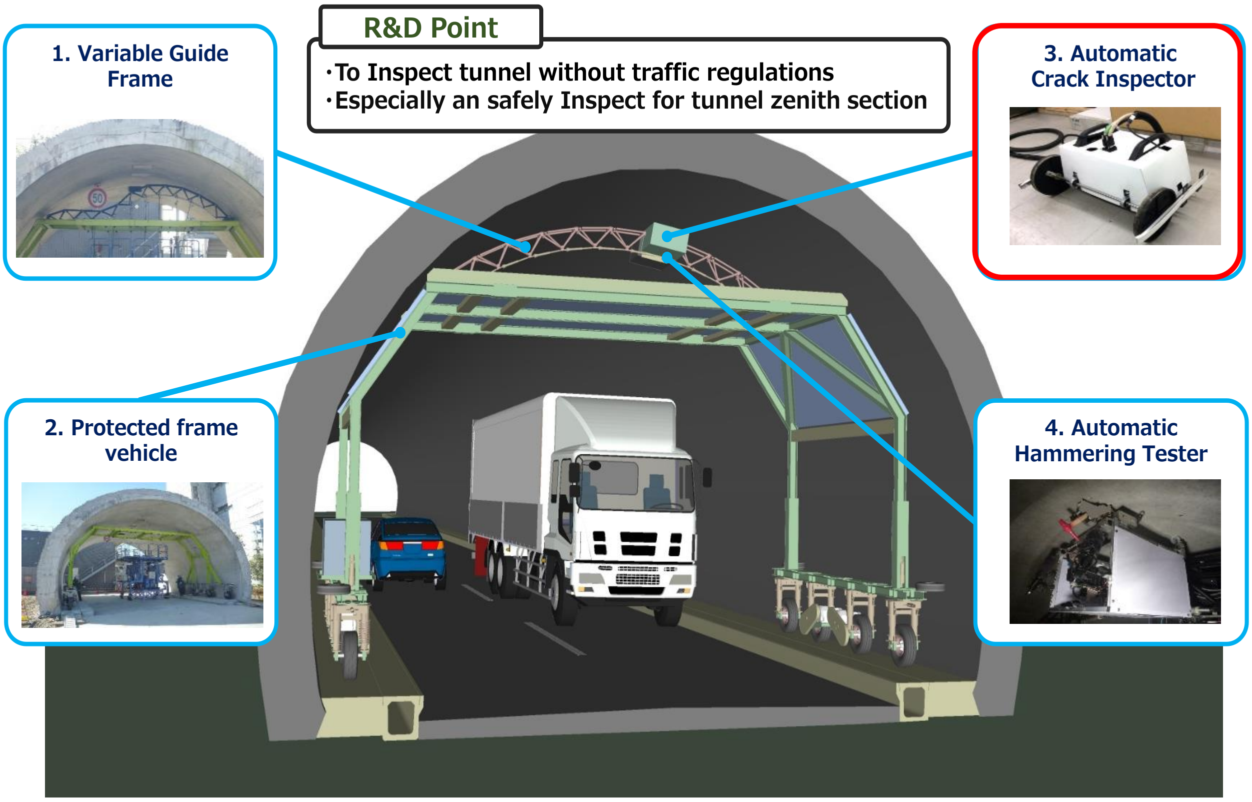

Fig. 3 Concept of our method of tunnel inspection (mobile light-section device is in red square at upper right)

The authors made the device for an automatic concrete crack inspection that can implement the mobile light-section method by combining the wheel and encoder, and robotic scanning of the lining concrete surface (Figure 2). Our image processing software for the device was configured as shown in Figure 3. An image is photographed according to the scanning distance, and the light-section processing is performed when the images are accumulated. Based on the generated depth image and color image, the cracks are automatically detected (see [3] for more details). The detection results are integrated on a stitched image with about 10 square meters, and are used for the measurement of the crack length and the investigation of the closed cracks that has a risk of chip out to a road. Our system could be performed these processes onsite.

Figure 4 shows an example of a color image and a depth image obtained by scanning the same object. In the depth image, it is possible to distinguish between real cracks and simulated cracks drawn with felt pen (black, brown and green) and chalk (white) near the actual cracks. In order to verify the performance of the automatic inspection of cracks by this device, for each of the 10 concrete test samples, the detection rate (the detected crack length dividing by the actual crack length) and the false detection rate (the number of erroneously detected pixels divided by the total number of detected

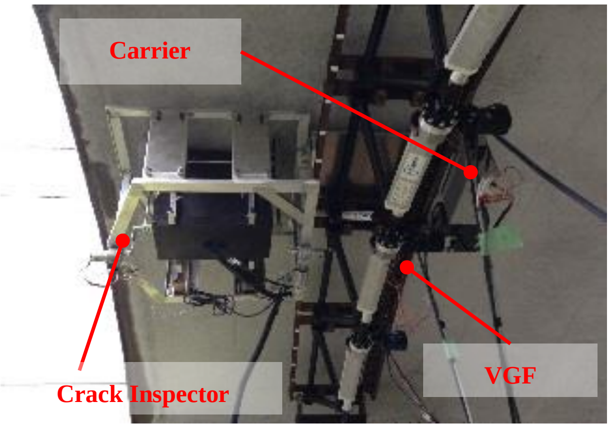

Figure 1. Our light-section device prototype

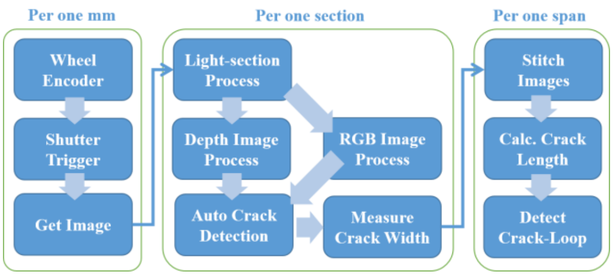

Figure 2. Crack inspection flow by our device

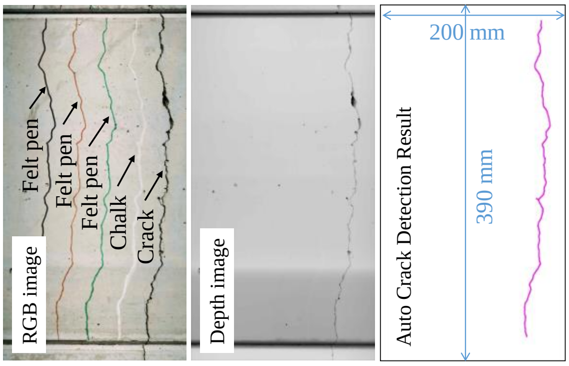

Figure 4. Automatic crack detection result example by using a concrete test sample with simulated dirt lines and a chalk line

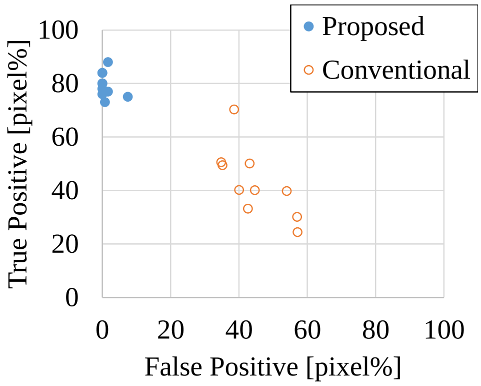

Figure 5. Automatic Crack detection accuracy by using 10 concrete test samples

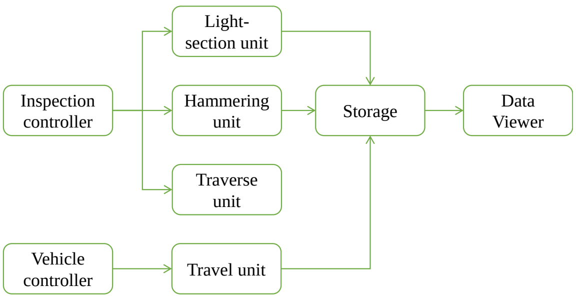

Figure 6. Inspection process by VGF vehicle

pixels) was evaluated and plotted as shown in Figure 5. The cracks were detected by using only the depth image. On the other hand, for comparison, the detection rate by a commercial software and the color images was also shown in the figure. The crack detection rate by our method was greater than 73% and the false detection rate was less than 8%, both of which were confirmed to be superior to those of the conventional method. The main cause of false detection was surface bubbles near the cracks. However, the misdetection of felt pen or chalk was 0%.

Figure 6 shows an inspection process for our system. The variable guide frame vehicle has 4 features. The 1st is a variable guide frame. It enables avoidance of speed signs and luminance and so on. The 2nd is a protected frame vehicle. It enables traffic-free inspection and ensures safety of road users. He 3rd is the mobile light-section device. The 4th is the robotic hammering device (see [5] for the details). These features enables robotic tunnel inspection method we have proposed.

3 Test on NATM simulated tunnel

The depth image and color image were obtained by scanning the lining concrete surface using the light-section method on the actual-size simulated tunnel made by NATM method. The scan range was ~5.4 m in the circumferential direction of the arch part, as shown in Figure 9, and ~10.3 m in the axial direction. Considering the overlapping portion in the short axis direction, the effective scan width was 400 mm. 26 strips of image were taken and stitched as Figure 7 and 8. A white part on these figures is a place of speed sign.

Based on the obtained texture/depth images, crack detection software is used to automatically detect the cracked parts from the images of each scan; the width and length of the crack are obtained by counting the detected pixels semi-automatically as shown in Figure 9. This was done by an operator specifying two points on the screen and automatically counting the pixels in a straight line connecting the two points. The width and length of the cracks thus obtained were compared with those obtained using the conventional method (close visual observation) by a skilled checker.

The measurement results of the crack length are shown in Figure 9. The upper numbers on the side of the cracks are crack width. The lower ones are crack length ratio against with the close visual inspection results obtained by skilled workers as shown in Figure 10. When comparing the measured value by our method with the value by skilled workers, it was found that the crack length shorter than the values obtained by a skilled worker, however, bold cracks (width >= 0.5) in results are almost same.

4 Test on tunnel made by piling method

The depth image and texture (color) image were also obtained on an actual road tunnel made by conventional piling method. The scan range was ~3.4 m in the circumferential direction of the arch part, and ~3.7 m in the axial direction. The effective scan width was 400 mm. 10 strips of image were taken and stitched as Figure 11 and 12. A white part on these figures is a place of speed sign.

Based on the obtained texture/depth images, crack detection is used to automatically. The length of the

Figure 7. Panoramic texture image of a tunnel lining concrete made by NATM method

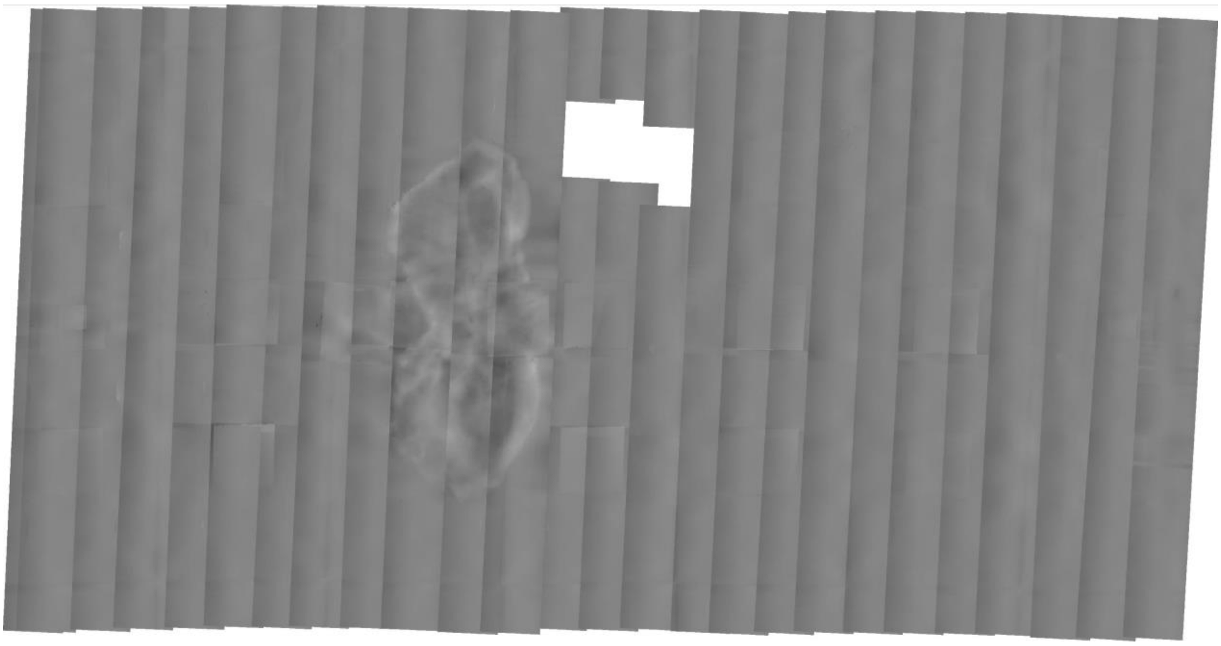

Figure 8. Panoramic depth image of a tunnel lining concrete made by NATM method

crack are obtained by the same way as shown in Figure 12. The values on the figure means the same parameters of the Figure 9.

The crack detection rates of the above two tunnels and CMI tunnel results (reported in [3]) are shown in Figure 13. The rate was over 90% when excluding the cracks with a width of less than 0.5 mm and with an efflorescence. The false-negative of the detection especially occurred for the crack with an efflorescence. The most of the false-positive occurred at the bug-holes in concrete near the cracks or the construction joints. Currently, we are investigating ways to distinguish the cracks and the bug-holes more clearly using a cord-like structure of the cracks and a circularity of the bug-holes.

5 Conclusions

We developed an automatic crack detection method by using both depth and texture images. In order to obtain these images in about 0.1 mm/pix resolution

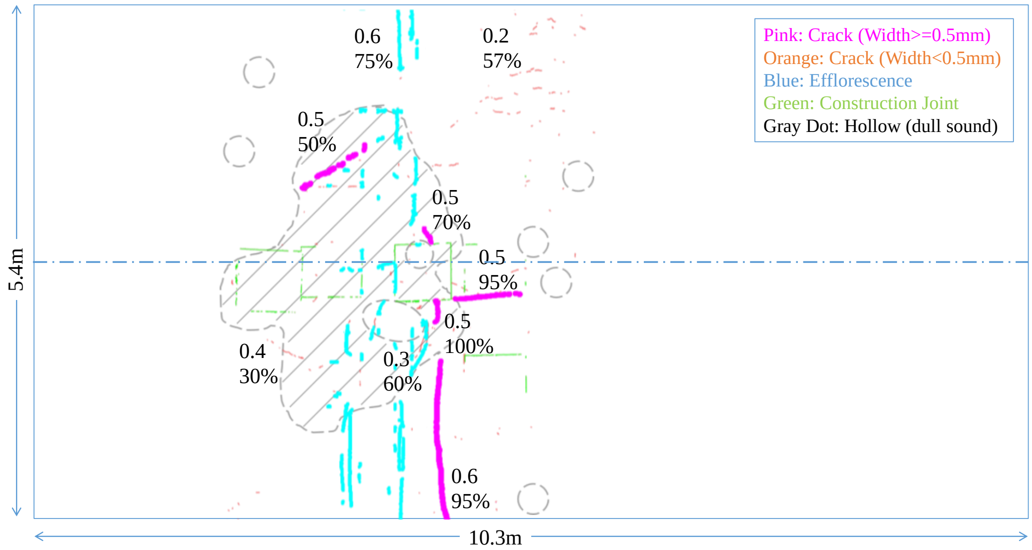

Figure 9. Inspection result by our method with crack width and crack detection rate

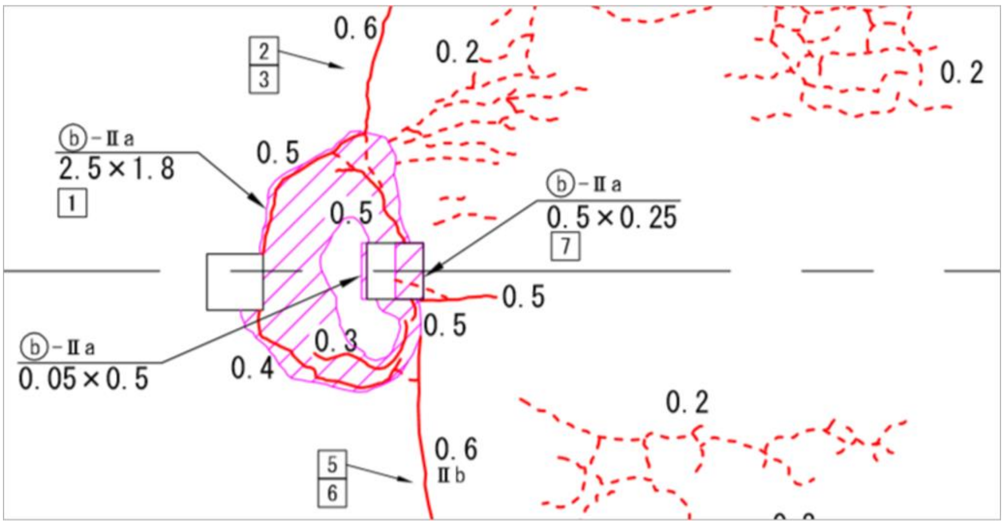

Figure 10. Inspection result by conventional method by inspection experts

quickly, we developed crack inspection device based on the light-section method. We inspect two type of tunnel ceilings by our device equipped with the variable guide frame vehicle. These results showed that the proposed technique has a crack detection performance equivalent to that of humans.

Currently, the authors are brushing-up the tunnel inspection method using this device for improving the detection accuracy of crack detection software.

This work was supported by Council for Science, Technology and Innovation, “Cross ministerial Strategic Innovation Promotion Program (SIP), Infrastructure Maintenance, Renovation, and Management.” (Funding agency: NEDO)

References

[1] Japan Ministry of Land, Infrastructure, Transport and Tourism. The maintenance of national road network in Japan. http://www.mlit.go.jp/en/, Accessed: 31/1/2018.

[2] Japan Science and Technology Agency, List of Research and Development Teams - Infrastructure Maintenance, Renovation and Management. http://www.jst.go.jp/sip/k07_kadai_dl_en.html, Accessed: 31/1/2018.

[3] Inoue D., Ueno T. and Nakamura S. Experiment on Mobile Light-section Device for Automatic Crack Inspection of Actual-size Tunnel Lining Concrete. In *Proc. of 34th Int. Symposium on*

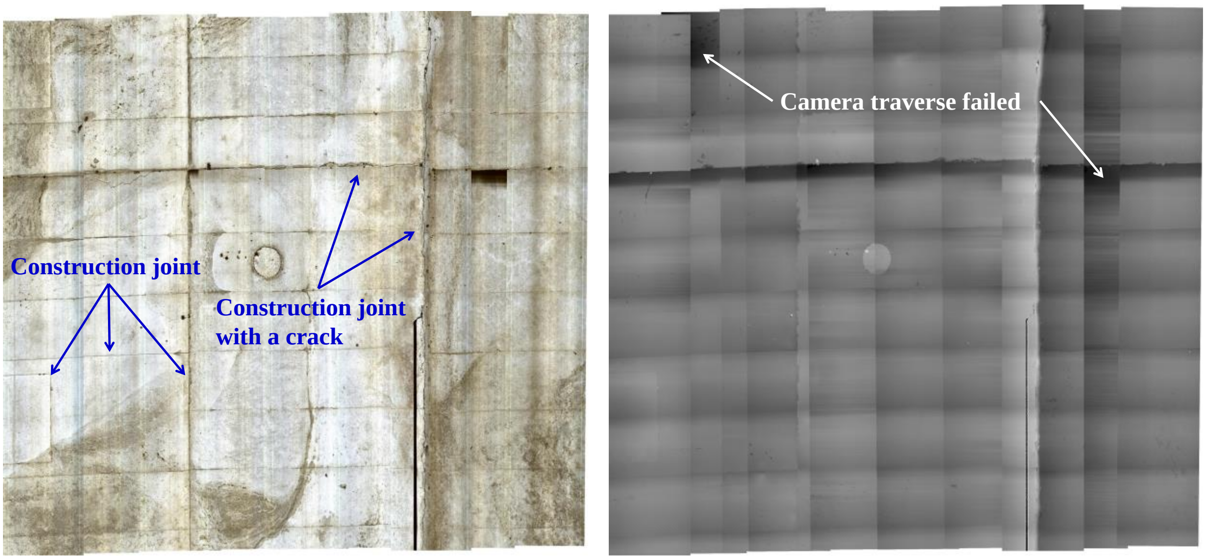

Figure 11. Panoramic image of a tunnel made by conventional piling method (L: texture, R: depth)

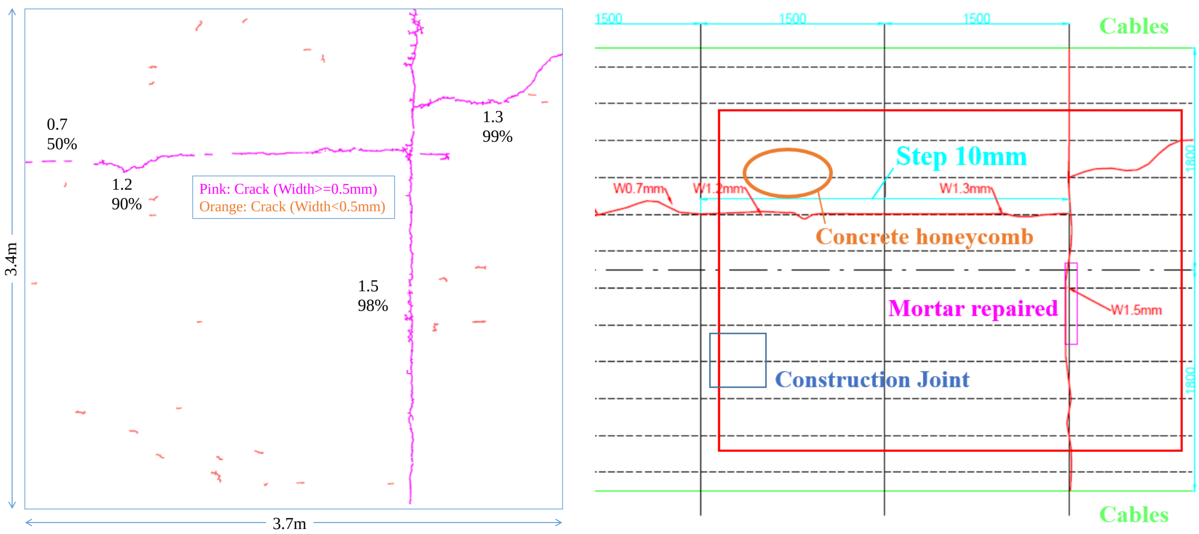

Figure 12. Crack inspection result with crack width and detection rate (L: by our method, R: by experts)

Automation and Robotics in Construction, 2017.

[4] Nakamura S., Takahashi Y., Inoue D. and Ueno T. The Variable Guide Frame Vehicle for Tunnel Inspection. In *Proc. of 34th Int. Symposium on Automation and Robotics in Construction*, 2017.

[5] Takahashi Y., Nakamura S., Ogawa Y. and Satoh T. Velocity Control Mechanism of the Under-actuated Hammering Robot for Gravity Compensation. In *Proc. of 34th Int. Symposium on Automation and Robotics in Construction*, 2017.

[6] Takahashi Y., Maehara S., Ogawa Y. and Satoh T. Concrete Inspection Systems Using Hammering Robot Imitating Sounds of Workers, In *Proc. of 35th Int. Symposium on Automation and Robotics in Construction*, 2018.

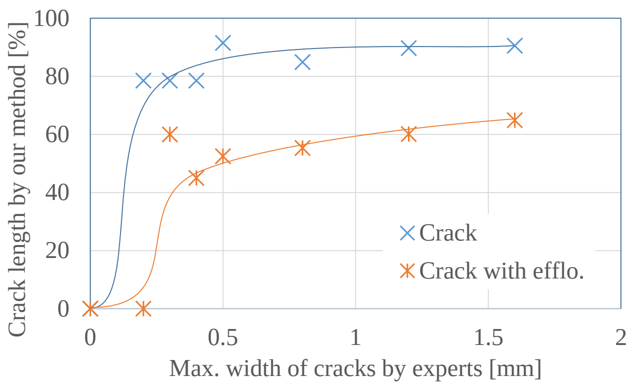

Figure 13. Crack length against the max width