Dams and Reservoirs under Changing Challenges – Schleiss & Boes (Eds)

The investigation method of hydroelectric facilities by using digital camera

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ABSTRACT: In surface investigation of the concrete structures, an investigator has to often access a high place. In such a case, methods such as temporary scaffold and rope access are adopted. However, these methods are expensive, and dangerous. In recent years, the performances of a digital camera and image processing technology have accomplished remarkable progress. So the authors attempted to apply the photographic image measurement technique both for the surface of a dam and the concrete lining of a tunnel.

1 INTRODUCTION

The KANSAI Electric Power Co. (hereinafter called KEPCO), own 149 hydroelectric power plants in Japan and the total output of hydropower is about 8195 MW. KEPCO has Inspection and Monitoring System divided into three portions, such as patrol, inspection and deterioration diagnosis. The patrol is conducted daily and monthly, and the inspection is conducted annually. The deterioration diagnosis is conducted once in several years and we assess the conditions of facilities in total.

KEPCO conducts deterioration diagnosis at our concrete dams once every 10 years, and we conduct crack monitoring of the concrete structures in the deterioration diagnosis. In conventional investigation methods, investigators have to often access a high place. In such a case, methods such as temporary scaffold and rope access (Figure 1) are adopted. These methods, however, are expensive and time consuming, and danger is accompanied. Therefore, the improvement of the investigation methods is required.

Then, the authors developed a photographic image measurement system to check the surface of concrete, and KEPCO adopts the system in actual investigations since 2009.

This newly developed system is a combination technology of a total station and a digital camera (Tsugio et al. 2008). First, images taken with a digital camera are transformed into the images viewed from the front on the PC, based on three-dimensional coordinate data obtained by a total station. Secondly, the individual front view images are stitched into a total image of the structure. Finally, the crack locations, the crack total lengths and the crack widths are found from the stitched image.

KEPCO has conducted the photographic image measurement at 16 dams and a waterway tunnel in 2009 and 2010. Authors report the investigation results here.

2 PRINCIPLE OF PHOTOGRAPHIC IMAGE MEASUREMENT TECHNIQUE

In the beginning, authors explain the principle of the image measurement technique. This technique provides synthesized front view images of the components of the structure. The technique uses images taken by high resolution digital camera and the coordinates measured by an automatic surveying instrument so called total station (Figure 2), and compensates angle, curvature and scale, then synthesizes images by image processing unit (Figure 3). Then the lengths of the cracks are measured by tracing the recognizable cracks on a synthesized

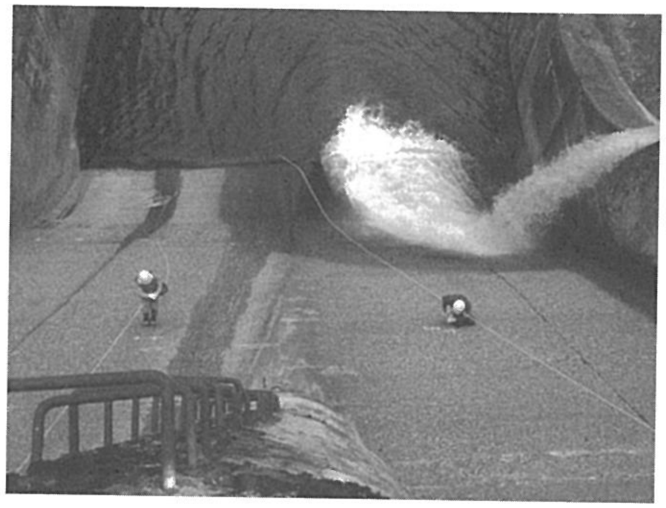


Figure 1. Dam surface inspection by rope access.

Digital camera Total station

Figure 2. Image measurement equipment.

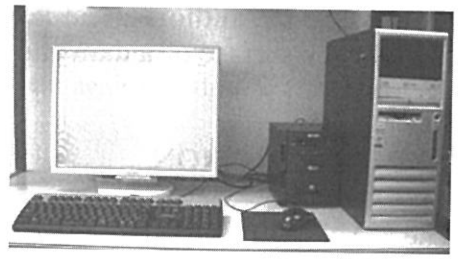


Figure 3. Image processing unit.

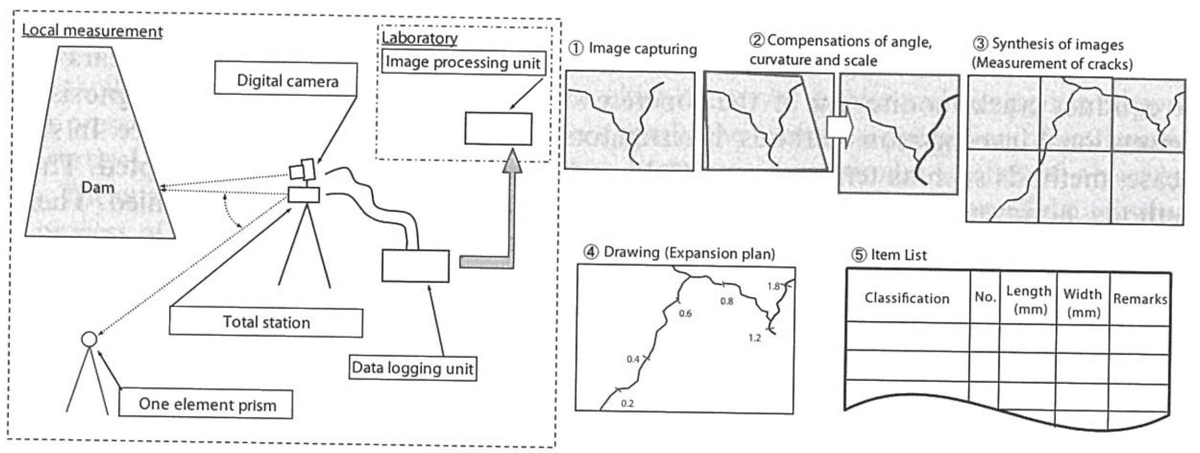


Figure 4. Flow of image measurement technique.

image displayed on a monitor and the widths of the cracks at the position that can be recognized on the cracks with the naked eye are evaluated (Figure. 4). Main instruments of the system are a single-lens reflex digital camera, a non-prism total station (instrumental tolerance equals plus or minus 3 mm and plus or minus [$2 \times 10^{-5} \times$ distance]), an image processing unit and a data logging unit (Table 1).

The quality of an image mainly depends on the resolution of the digital camera and the telephoto lens. When same area is captured, the quality of the image becomes higher if the digital camera is equipped with more pixels. The resolution of a pixel (the length of a side of a pixel) of the digital camera equipped with $2{,}900 \times 4{,}350$ pixels (12.6 million pixels) is around 1.4 mm when the rectangular surface of a concrete structure with the dimensions of $4 \text{ m} \times 6 \text{ m}$ is captured. Figure 5 shows an evaluation method of crack width. Since the individual pixel of the digital image usually has 256 gradation steps for each three primary color (RGB), the width of

Table 1. Specification of main equipments.

Equipment	Specification
Digital camera	Single-lens reflex digital camera: 12.6 million pixels
Telephoto lens	Autofocus (24–85, 80–400 mm)
(Non-prism) Total station	Instrumental tolerance: [$3 + \text{or} - 2 \times 10^{-5} \times \text{distance}$] mm
Data logging unit	Note PC (CPU: Core Solo U1300, Memory: 1 GB, HDD: 60 GB)
Image processor unit	Desktop PC (CPU: Pen4, 3.2 GHz, Memory: 2 GB, HDD: 250 GB)

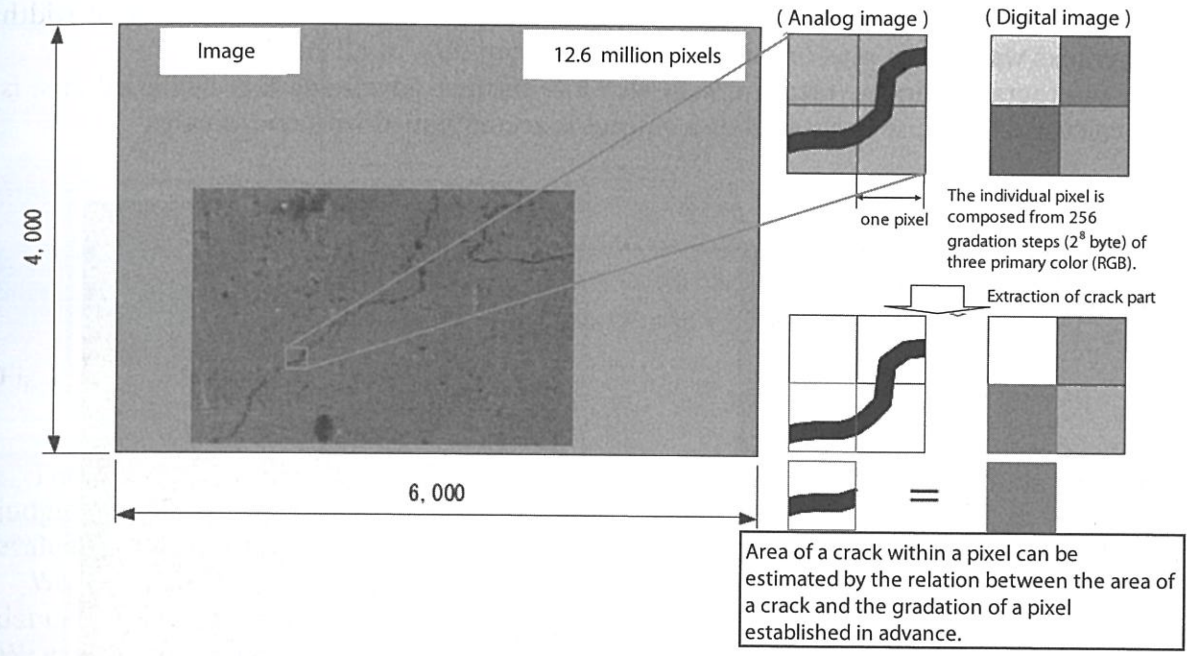


Figure 5. Evaluation method of crack width.

a crack which is narrower than the resolution can be measured if the relation between the ratio of the crack over to one pixel and the gradation level of the pixel is established (Hiroshi 2004).

In the case of using digital single-lens camera which is attached 400 mm telephoto lens, it is possible to identify the crack width of 0.2 mm if the image is taken 120 m away. The detection ratio of cracks of 0.2 mm width or wider is more than 90% by limiting the angle of view narrower than 7.3 m.

3 APPLICATION EXAMPLE OF PHOTOGRAPHIC IMAGE MEASUREMENT TECHNIQUE

3.1 *Dam deterioration diagnosis*

KEPCO conducts crack monitoring of the concrete structures in the dam deterioration diagnosis by using this photographic image measurement technique since 2009. KEPCO has already conducted the initial investigation in 16 dams out of 39 concrete dams owned by KEPCO. Here are the results to verify whether the photographic image measurement has an advantage over the conventional method by rope access.

The photographic image measurement technique was applied to aerial surfaces of two dams with a different size (surface areas of the two dams sum up to about 10,000 m^2 in all). Images were captured from where a captured image area was smaller than a rectangle of 4 m × 6 m, the angle to the subject was smaller than 45 degrees and distance from the subject was closer than 150 m. About 1,500 images of the two dams were captured in seven days. Figure 6 shows distant view on the dam downstream side. Compensations of angle, curvature and scale were carried out to all the images, and these images were synthesized into several front view images. Cracks of 0.2 mm width or wider could be found individually while stains, concrete joints and formwork marks were checked on a monitor. Figure 7 shows an example of a sketch of cracks on a synthesized image after the compensation of angle, curvature and scale.

Moss and stain did not prevented any cracks from being found in the verification. Some painted concrete areas with reflection of sunlight prevent some cracks from being found. In such cases, images were captured again at other time considering the reflection of sunlight. Comparing all found crack lengths of the two dams with opening of 0.2 mm width or wider with those found by the conventional method, each deviation was within plus or minus 10% in about 97% of all cracks and the deviation of accumulated length of individual components of the dams varies from minus 2.1% to plus 6.2% (Table 2, Figure 8). The deviation of width of the cracks was within plus or minus 0.1 mm in about 98% of all cracks.

The photographic image measurement also has another advantage that degraded area is easily calculated because each pixel of a subject is accompanied with coordinates.

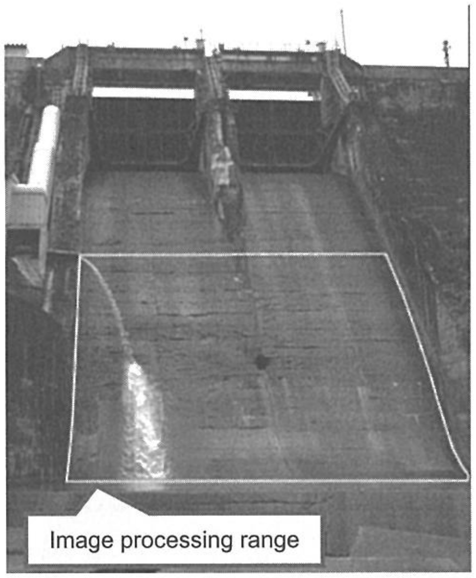
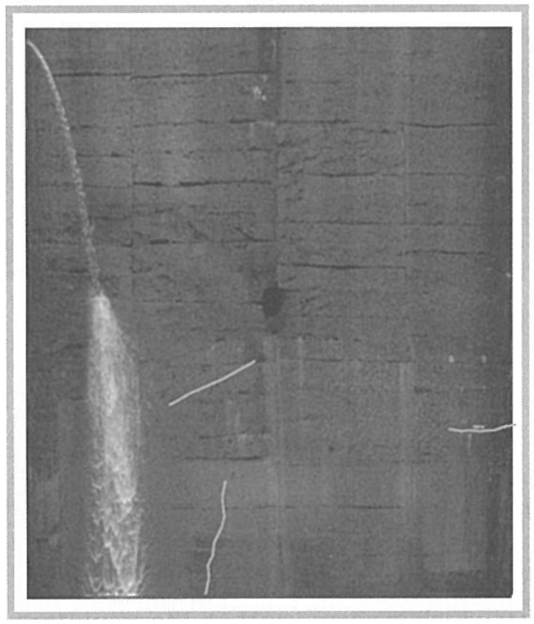


Figure 6. Distant view on the dam downstream side.



(Image processing area: about 378m² (The number of images:28))

Figure 7. Dam downstream side image after image processing.

Table 2. Comparison results of the crack of the two dams.

Crack	No.	Length (mm) Conventional method	Length (mm) Image measurement	Deviation (%)	Maximum widtht (mm) Conventional method	Maximum widtht (mm) Image measurement	Deviation (%)
	1	8, 100	8, 006	−1. 2	0. 2	0. 2	+0. 0
	2	7, 050	6, 964	−1. 2	0. 2	0. 2	+0. 0
	3	2, 750	2, 981	+8. 4	0. 3	0. 2	−33. 3
	4	2, 500	2, 406	−3. 7	0. 2	0. 2	+0. 0
	5	2, 500	2, 393	−4. 3	0. 2	0. 2	+0. 0
	6	2, 200	2, 245	+2. 1	0. 2	0. 2	+0. 0
	[illegible]	[illegible]	[illegible]	+6. 3	0. 3	0. 4	+33. 3
	14	8, 850	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	15	3, 250	3, 379	+4. 0	0. 2	0. 2	+0. 0
	16	5, 050	4, 886	−3. 2	0. 2	0. 2	+0. 0
	17	2, 450	2, 268	−7. 4	0. 3	0. 2	−33. 3
	18	2, 700	2, 883	+6. 8	0. 2	0. 2	+0. 0
	19	1, 850	1, 720	−7. 0	0. 2	0. 2	+0. 0
	20	3, 300	3, 328	+0. 8	0. 5	0. 4	−20. 0
Total / average		93, 450	91, 987	−1. 6	0. 275	0. 240	−10. 3

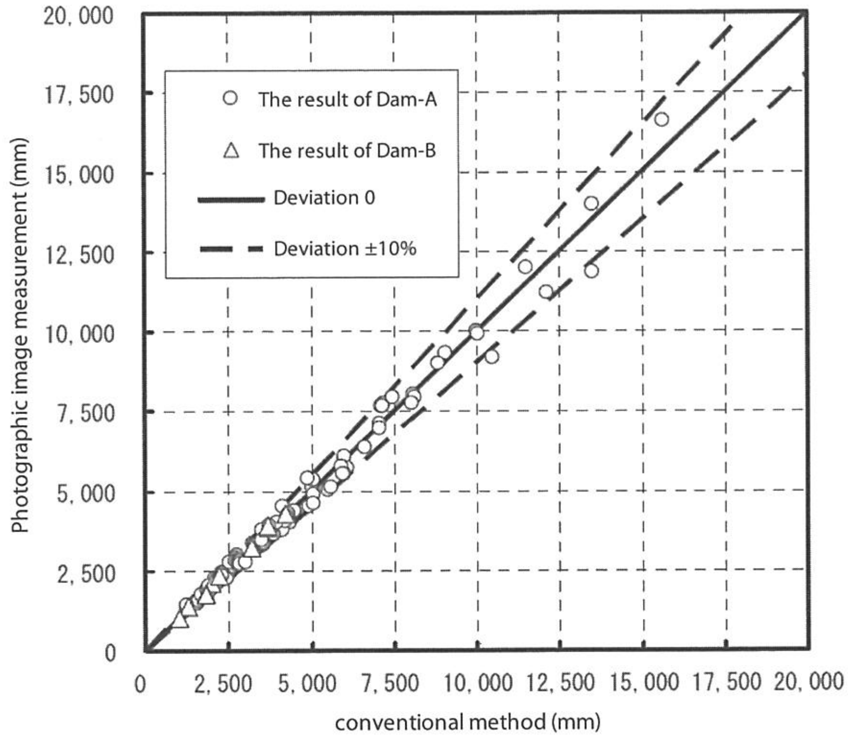


Figure 8. Comparison results of crack length.

The image measurement costs approximately 30% lower than the conventional method judging from the rough estimate of labor costs. Now we are conducting more detailed cost evaluation of the photographic image measurement.

We are also developing a database system with a retrieval function in which electronic data such as digital images and crack information are linked to drawings of the facilities. We expect the system help and save our maintenance work such as the comparison with the previous investigation.

3.2 *Waterway tunnel inspection*

Next, authors show an application example for a waterway tunnel inspection. The KANSAI Electric Power Group is engaged in an O&M consulting business of an overseas hydropower IPP, the San Roque Multi-purpose Project in Philippines, and in the waterway tunnel inspection of the San Roque power plant, the photographic image measurement has been conducted in 2009. Table 3 and Figure 9 show the outlines of the San Roque Dam and a longitudinal section profile of the waterway tunnel. Because the inside diameter of the waterway tunnel, which is pressure tunnel with concrete lining, is 8.5 m, it is necessary to set up a tall temporary scaffold for visual monitoring of cracks in order to observe the crown of the tunnel in detail. Since dewatering period of the waterway tunnel is a very short time, and a hatch of the waterway tunnel is less than 1 m in diameter from which inspection equipment are brought in. It is difficult to carry out enough research in a short time, so KEPCO introduced the photographic image measurement. The image measurements were carried out at sections where the bedrocks were weak and many cracks were found. Two locations were selected for the photographic image measurement, which were 29 m wide and 3 m high, 21 m wide and 3 m high respectively, with a total area of 150 m^2. Because the surface of the tunnel was stained with the mud, images were taken after cleaning the surface by high-pressure water washing. The measurement was completed in about three days. After bringing back the images to Japan, authors conducted image processing in our laboratory. Because the waterway tunnel has a simple circular cross section and the concrete surfaces had formwork marks, the image syntheses were relatively easy.

Table 4 and Figure 10 show comparison results of some of the data obtained from the image measurement in 2009 and 2010. As for the results of 2010, authors couldn't distin-

Table 3. Outlines of the San Roque Dam.

Item	Outline
Dam type	Center Core type Rock fill Dam
High (m)	200
Crest length (m)	1,130

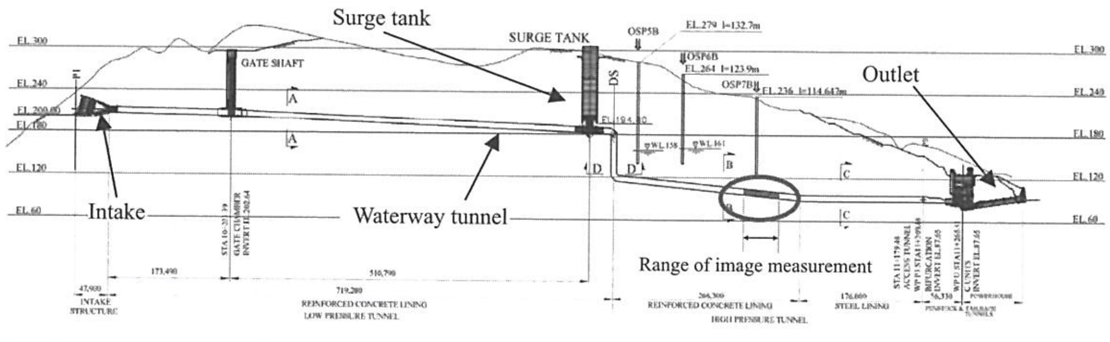


Figure 9. Longitudinal section profile of the waterway tunnel.

Table 4. Comparison of waterway tunnel crack data.

No.	Length (mm) 2009	Length (mm) 2010	Deviation (%)	Maximum width (mm) 2009	Maximum width (mm) 2010	Deviation (%)
1	1167	1220	4.3	0.2	0.2	0.0
2	1138	1131	−0.6	0.6	0.6	0.0
3	1999	2030	1.5	0.4	0.4	0.0
4	1725	1691	−2.0	0.2	0.2	0.0
5	9959	9516	−4.7	0.8	0.8	0.0
6	1255	1178	−6.5	0.8	0.8	0.0
7	7150	7443	3.9	0.8	0.8	0.0
8	6995	8077	13.4	0.8	0.8	0.0
9	3940	4337	9.2	0.8	0.8	0.0
10	1765	1905	7.3	0.4	0.4	0.0
11	3084	3150	2.1	0.6	0.6	0.0
12	1833	1723	−6.4	0.2	0.2	0.0
13	–	954	–	–	0.4	–
Total/average	42010	44355	5.3	0.508	0.538	5.7

guish any change of crack width. But authors found slight progress of the length of the some cracks, and found one new crack. Seeing images of 2009 much more closely, authors could find a tiny sigh of a crack at the new crack position. Since the slight cracks were confirmed when images of the previous year were investigated in detail, it is assumed that the finding of the new crack is due to using a higher resolution camera (from 12.6 million pixels to 16.0 million pixels) or the different condition of the wall washing. Therefore, authors finally judge the tunnel keeps sound conditions.

Since the San Roque Power Plant, of which operation was started in 2003, is a relatively new power plant, significant degradation progress was not observed in the inspection. KANSAI could record the concrete condition at a relatively early stage. This data will be very useful at future stage in which degradation of the plant will advance.

The photographic image measurement at the San Roque waterway tunnel is the first-time experiment for KANSAI to conduct the measurement more than twice at the same point. We are firmly convinced that the database system is very useful by reconfirming as much as by comparing the past data.

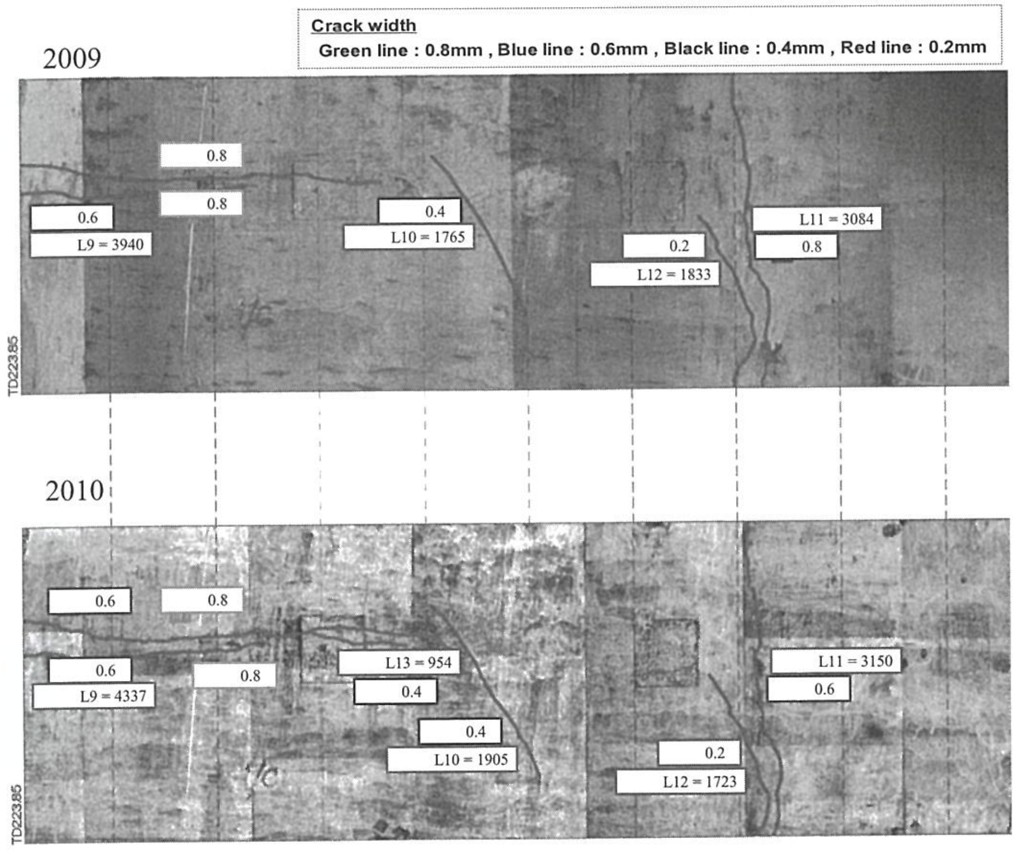


Figure 10. Result of waterway tunnel image analyses.

Authors have given on-the-job training of taking the images to the local civil engineer of the San Roque Multi-purpose Project. From now the local engineers will take and send the images to us and authors will conduct image processing in our laboratory. KANSAI can share the wide variety of the database both in Philippines and in Japan, and it makes the O&M more reliable and effective.

4 CONCLUSION

In this study, we have developed the photographic image measurement applying both for the surface of a dam and the concrete lining of a tunnel and have confirmed the availability with a certain level of the accuracy. We believe the new measurement ensures the safety of field works, the accuracy of observe data and economic efficiency.

With the information obtained from this new method, we are attempting to establish more reliable operation and maintenance of concrete structures. We are also going to pursuing more laborsaving method and expand applicable objects of the photographic image measurement by modifying the equipment and devising methodology of measurement and data processing.

We think a subject of future investigation is how to detect the depth of cracks, which is one of key factors to the soundness of concrete structures.

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