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DEVELOPMENT OF CRACK OBSERVATION METHOD USING VIDEO CAMERA FOR CONCRETE ARCH DAM (*)

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1. INTRODUCTION

An arch dam stores water by the arch action of a thin concrete wall. The concrete of an arch dam, therefore, is continually subjected to greater stresses than the concrete used in other types of dams. The arch dam reported in this paper has minor cracks that are thought to have been caused by drying shrinkage and thermal stress. Visual observation results concerning the progress of cracking and displacement measurement results obtained with plumblines, however, have confirmed that there is no problem in the stability of

(*)*Developpement d'une method pour observer les fissures d'un barrage-voute en beton en utilisant le caméscope* the dam.

In the case of a large arch dam, however, it is very difficult to visually observe the entire downstream face of the dam to detect cracks. It is believed that accurate knowledge on crack behavior and the progress of cracking will prove helpful in detecting anomalies of a dam when evaluating the state of aging facilities and the post-quake safety of the dam. As an auxiliary means of visual inspection, therefore, we have developed a system that makes it possible to observe even minor cracks from a distant location by using a video camera equipped with a precision super-telephoto lens.

This paper describes the newly developed crack observation system capable of covering the entire downstream face of an arch dam, reports crack observation results obtained by using the crack observation system and evaluates the performance of the system.

2. PROBLEMS IN VISUAL OBSERVATION OF ARCH DAM

At the dam reported in this paper, the dam body, the foundation around the abutment zones and the outlet facilities are inspected periodically, and special inspections are conducted after an earthquake, flood or heavy rain that exceeds predetermined limits in accordance with the standard for the management of dam structures stipulated by the Japan Commission on Large Dams (JCOLD). In periodic inspections and special inspections, it is necessary to inspect, as one of the check items, the concrete surface to check whether there are cracks and examine the state of cracks. This crack inspection is conducted in the form of visual observation.

For the purpose of such visual observation, the downstream face of the dam has projecting narrow catwalks shown in Fig. 1. In general, such catwalks are widely spaced apart, usually at intervals of 15 m or so. It is almost impossible, therefore, to cover the entire downstream face of the dam in detail in detecting and observing cracks.

Fig. 1

Catwalks on the downstream face of an arch dam

Passerelles au parement aval d'un barrage-voûte

3. CRACK OBSERVATION METHOD TO COVER THE ENTIRE DOWNSTREAM FACE

In order to observe all cracks in the downstream face of the arch dam, a new crack observation system has been developed. The system images the entire dam by using a video camera equipped with a precision super-telephoto zoom lens located about 100 m downstream, joins together the images thus obtained through automatic deformation processing, and generates crack maps showing accurate location, width and length of each crack. The reason why a video camera instead of a digital camera is that video imaging is fast and inexpensive because the video camera is capable of shooting 30 frames per second.

3.1. Video imaging method to cover the entire downstream face of a dam

3.1.1. Imaging Equipment

The imaging equipment consists of a video camera, a telephoto zoom lens, a laser ranging system, a camera positioning device by which to ensure full coverage of the target area, a personal computer and specially developed software to control the camera positioning device, a recording system, and a tripod (Fig. 2). Of these system components, the video camera and the telephoto zoom lens are precision items comparable to the ones designed for television station applications.

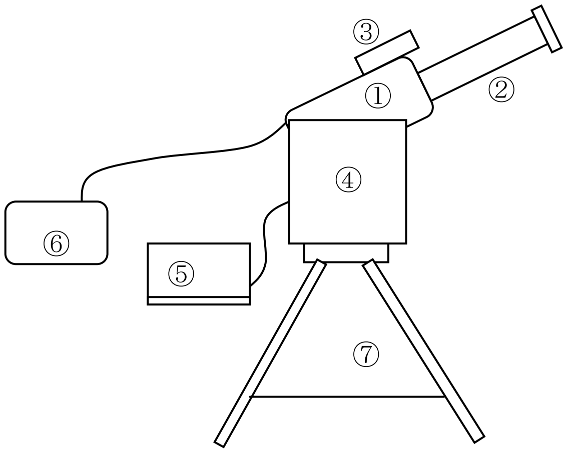

Fig. 2

Video recording system

Système de l'enregistrement des images prises par le caméscope

1	High-performance video camera	*1*	*Caméscope à hautes performances*
2	Super-telephoto zoom lens	*2*	*Téléobjectif à grossissement super*
3	Laser ranging system	*3*	*Système de télémètre à laser*
4	Camera positioning device	*4*	*Appareil de contrôle du positionnement du caméscope*
5	Personal computer for camera positioning control	*5*	*Ordinateur personnel pour contrôler le positionnement du caméscope*
6	Video recorder	*6*	*Magnétoscope*
7	Tripod	7	*Tripode*

The camera positioning device, which is secured on the tripod, is a motorized device for pointing the camera up and down and laterally. This device automatically positions the camera according to the information entered in advance into the personal computer used solely for controlling camera positioning. Captured images are recorded by the video recording device as digital video images.

3.1.2. *Optimum Shooting Location and Width Coverage*

In order to find the optimum shooting location, test shooting was conducted from locations 50 m, 100 m and 200 m away from the dam, and the accuracy of the images obtained was compared (Fig. 3). In order to determine the optimum width of concrete surface to be covered by a single image, video shooting was done to cover concrete surface widths of 75 cm and 150 cm, and image accuracy was compared. The minimum crack width to be observed in images was defined as 0.2 mm because the minimum width category used in visual observation is 0.2 mm.

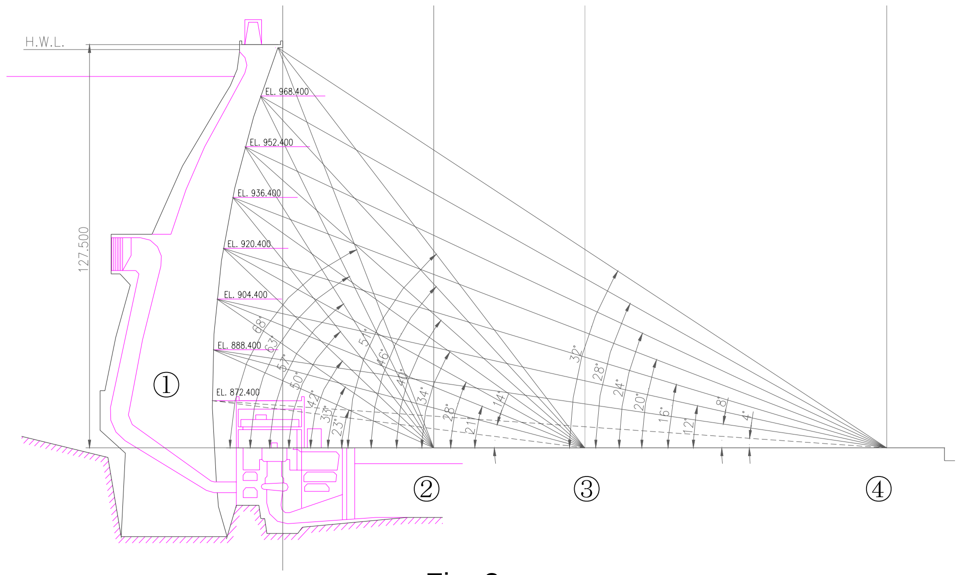

Fig. 3

Video camera locations in the field test for comparison of image accuracy

Loacalisation du caméscope pendant l'essai de chantier pour classer les précisions de l'image

1	Arch dam (cross section)	*1*	*Barrage-voûte (profil en travers)*
2	50 m downstream from dam	*2*	*50 m d'aval du barrage*
3	100 m downstream from dam	*3*	*100 m d'aval du barrage*
4	200 m downstream from dam	*4*	*200 m d'aval du barrage*

As a result, it was found that the target accuracy to be able to check a crack of the 0.2mm width, can be achieved and video imaging can be completed quickly and at low cost by shooting from a location 100 m away from the dam to cover a concrete surface width of 150 cm. Since it was difficult to cover the entire dam from a single location because of obstacles, video imaging was done from four points at distances from the dam of around 100 m.

3.1.3. Imaging Procedure

With the aim of imaging the entirety of a large area such as the downstream face of an arch dam with consistent accuracy, the following procedure was used:

(1) Dividing the dam face into small imaging areas

In order to prevent width coverage and image accuracy from varying because of changes in camera-to-subject distance, the dam face was divided into small imaging areas. The concrete block joints were regarded as vertical boundaries of those imaging areas, and the catwalks were regarded as their horizontal boundaries (Fig. 4).

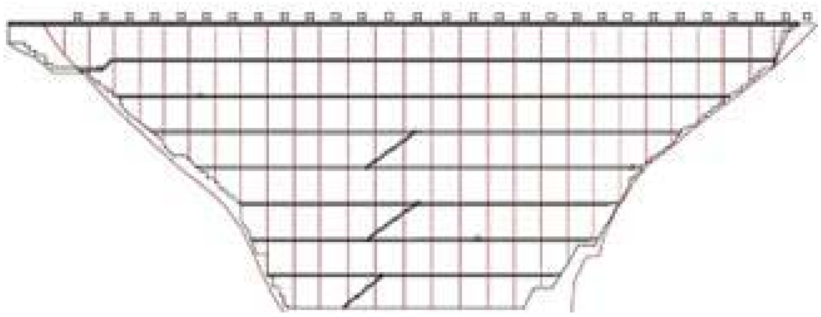

Fig. 4
Imaging areas
Zone de l'image

(2) Measuring horizontal and vertical angles and distances of four corners of each imaging area

The horizontal and vertical angles and distances of the four corners of each imaging area necessary for automatic imaging and image transformation are measured by using the camera positioning device and the laser ranging system. The data thus obtained are entered into the personal computer.

(3) Computing tilt and pan angles

The tilt and pan angles of the camera to cover the entirety of each imaging area are calculated with the personal computer.

(4) Automatic imaging according to computer-generated commands

According to computer-generated tilt and pan angle commands, each imaging area is imaged downward and the video camera is moved laterally so that the images of adjoining imaging areas overlap slightly (Fig. 5).This procedure is repeated to cover the entire downstream face of the dam. Fig. 6 shows how this imaging operation is carried out.

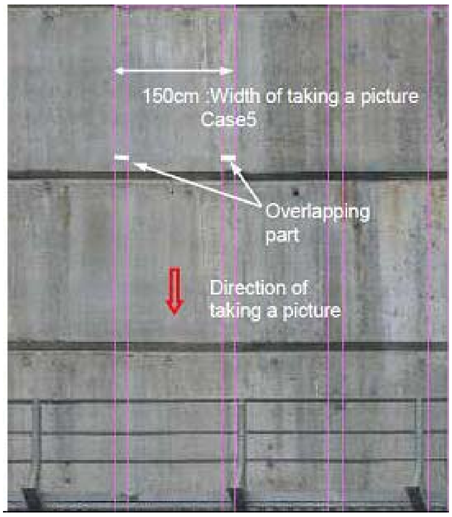

Fig. 5
Direction of camera movement *Direction du mouvement du caméscope*

Fig. 6
Video recording *Enregistrement des images*

3.2. Image joining method

Images were joined together by following the procedure described below.

(1) Transforming images

If a vertical wall is photographed by looking up at the wall, a picture showing a trapezoidal wall is obtained. Because concrete wall images like this cannot be joined together as they are, the trapezoidal shapes shown in all images in each imaging area are transformed into rectangles (Fig. 7). The image transformation software used for this processing has been developed specifically for this purpose.

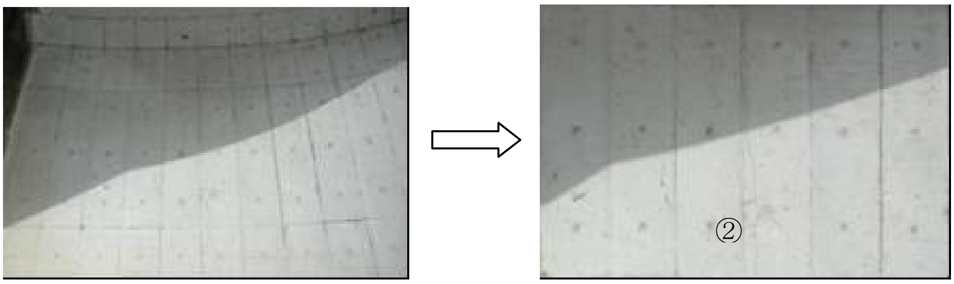

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Fig. 7
Image transformation
Transformation des images

1	Before	*1*	*Avant*
2	After	*2*	*Après*

(2) Joining images in each imaging area

The transformed images are joined together vertically (i.e., in the direction of video camera movement). To do this, the relatively distortion-free central regions of the images are joined together by use of specially developed software. As a next step, vertically joined image strips are joined together laterally in a similar way by use of the specially developed software. An example of a joined image thus obtained is shown in Fig. 8. As shown, the joined image is almost seamless.

Fig. 8
Example of image joining (joining of 150 images)
Exemple du couplage des images

(3) Joining area-by-area images

The area-by-area images obtained by image joining as described above are joined together to obtain an image of the entire dam face.

3.3. CRACK MAPPING METHOD

To generate a crack map from a joined image, specially developed software is used. The crack mapping procedure is as follows:
(1) Importing joined image

Joined area-by-area images are taken into the personal computer.

(2) Observing cracks on the computer display and generating a map

Imported images are enlarged on the computer display until cracks can be identified at the desired accuracy, and each crack is traced with a mouse or a stylus. Crack width is determined by displaying a crack scale on the computer display and comparing it with the imaged cracks. Displayed images are very clear, and cracks can be clearly visible on the display. An example of a displayed crack is shown in Fig. 9.

Fig. 9
Example of a crack shown in recorded image
Exemple d'une fissure trouvée dans l'image enregistrée

Fig. 10 shows an example of an image showing traced cracks. The numbers shown in the figure are automatically assigned to cracks when they are traced on the display screen. The crack lengths calculated automatically during crack mapping are also shown on the image.

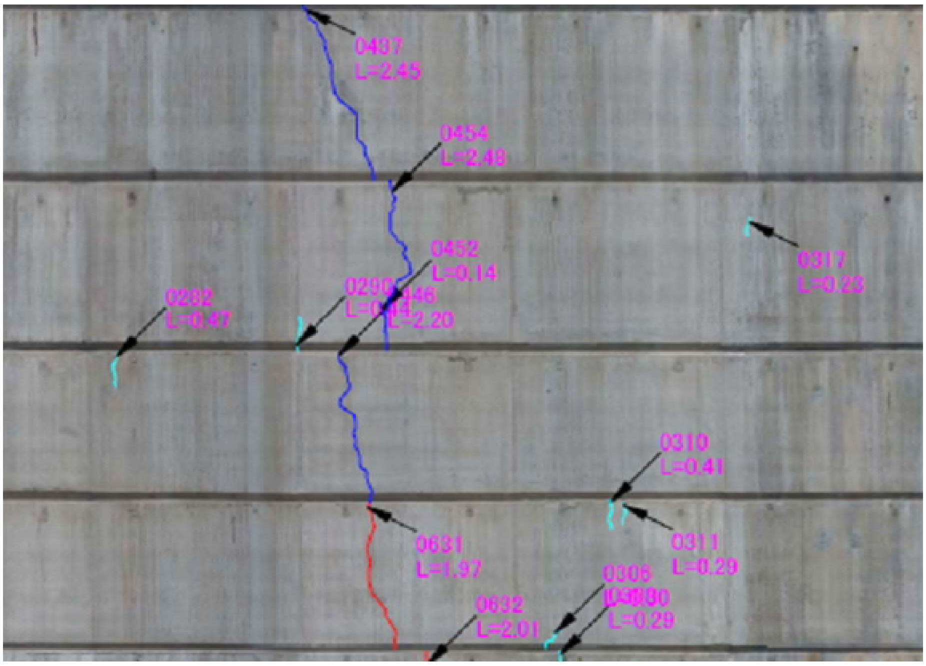

Fig. 10
Crack map
Carte des fissures

The start and end points and direction of each crack are also automatically recorded in terms of coordinates, and the results can be displayed as Excel spreadsheet data (Table 1). The crack widths shown in the table have been determined by comparison with the crack scale shown on the display screen as mentioned earlier.

Table 1

Numerical crack data

No.	Legend	Start point X	Start point Y	End point X	End point Y	Extension	Area	Long demension	Short demension	Direction
282	Crack B*	265.92	107.54	266.02	106.06	1.74				↑
290	Crack B	271.24	108.95	271.24	108.77	0.19				↑
300	Crack B	274.67	141.33	275.34	139.69	1.93				↑
302	Crack B	274.74	173.34	274.86	172	1.43				↑
310	Crack B	275.12	137.11	275.42	135.56	1.79				↑
311	Crack B	275.12	115.69	275.94	113.96	2.15				↑
317	Crack B	275.51	129.83	275.8	128.93	0.99				↑
360	spalling	243.57	135.56	243.69	136.44	1.91	0.08	0.89	0.12	
411	honeycomb	243.59	141.82	244.34	143.34	4.3	0.68	1.53	0.74	
412	honeycomb	243.59	137.58	244.76	139.7	6.15	2.06	2.12	1.17	
413	honeycomb	253.86	137.58	254.46	139.66	4.82	0.8	2.08	0.6	
414	honeycomb	254.74	137.94	256.12	139.6	5.24	1.28	1.66	1.39	
427	Rock poket	243.95	133.67	245.82	133.72	3.75	0.07	1.86	0.05	

(*)：Crack B :Crack (0.2mm or larger, smaller than 0.5mm)

4. CRACKS IN DOWNSTREAM FACE OF THE ARCH DAM: OBSERVATION RESULTS AND EVALUATION

Cracks in the downstream face of the higher-than-100-meter arch dam were observed with the newly developed, video-camera-based crack observation system. Crack observation results and their evaluation are shown below. Video shooting of the dam, excluding the portions of the dam that were not visible from a distant location because of obstacles, was mostly completed in one day.

4.1. OBSERVATION RESULTS

A crack map was drawn from the images recorded with the video camera. The cracks in the downstream face of the arch dam and an enlarged view of part of the crack map are shown in Fig. 11. The cracks superimposed on the video images are shown in Fig. 12.

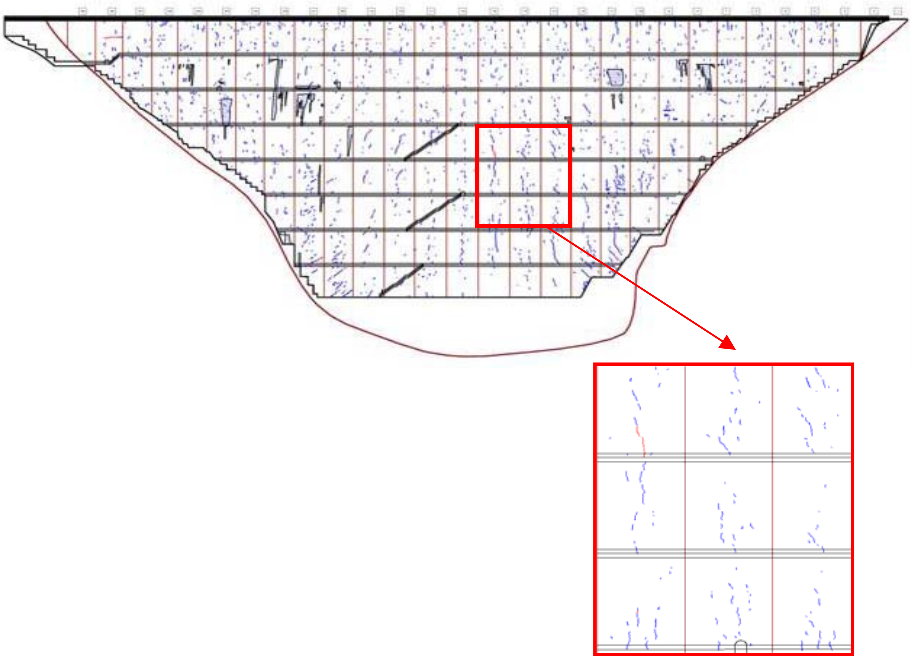

Fig. 11

Crack map of the downstream face of the arch dam

Carte des fissures du parement aval du barrage-voûte

Red line: crack width larger than 0.5 mm

Blue line: crack width in the range from 0.2 mm to 0.5 mm

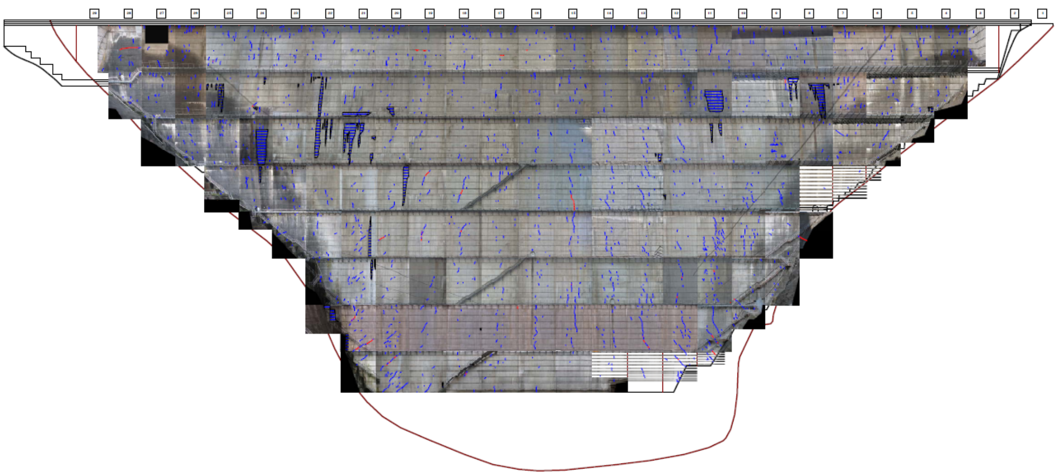

Fig. 12

Superposition of image and crack map

Superposition des images et la carte des fissures

In Fig. 11, Fig.12, regions wetted by spring water are shown in the upper part of the dam (the areas encircled by a blue line). The crack map indicates the following:

• There is no highly continuous crack.
• There is no leakage of water outflow from cracks.
• There are localized microcracks at the central part of each block.
• There are localized microcracks perpendicular to the bedrock surface on both sides of the lower part of the dam.

4.2. COMPARISON WITH CONVENTIONAL VISUAL OBSERVATION RESULTS

Fig. 13 compares the results of conventional visual observation of cracks in the downstream face of the arch dam and the observation results obtained from the newly developed system. As shown, the cracks excluding those near the catwalks could not be observed by the conventional visual observation method, while the newly developed system made it possible to observe cracks in any part of the dam face.

As shown, there are many cracks in the areas that cannot be observed by the conventional observation method. The comparison has revealed that many of these cracks are very small, and most of the cracks are not highly continuous.

The comparison has also revealed that there is little difference on width of crack between the visual observation results and the video-based observation results, and that 0.2 mm wide cracks can be identified by using the newly developed system.

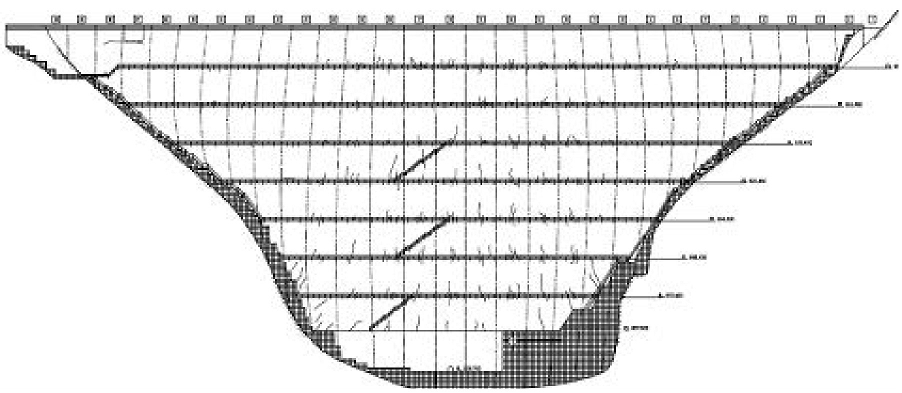

Fig. 13
Comparison with conventional visual observation results
Comparaison avec les résultats obtenus par l'observation visuelle conventionnelle

1	Conventional visual observation method	*1*	*Méthode conventionnelle de l'observation visuelle*
2	Newly developed observation method	*2*	*Méthode nouvelle de l'observation développée*

4.3. EVALUATION OF CRACK OBSERVATION RESULTS BY THE NEW METHOD

In order to evaluate crack observation results, it is important to conduct identical surveys several years later to check whether cracks have grown and new cracks have formed. From the initial observation result of this time, the evaluation reveals the following:

According to the crack observation results mentioned earlier, there are no highly continuous cracks, and most of the existing cracks are microcracks, which are thought to have been caused by drying shrinkage and thermal stress. These cracks, however, are somewhat continuous and are characteristically oriented in the same direction as follows.

• Inclined cracks

There are inclined cracks oriented toward the bedrock above the boundaries with the right- and left-bank rock surfaces and below a level roughly corresponding to two-thirds of the dam height. Most of the cracks have widths not greater than 0.5 mm, but there are also a very small number of local cracks having widths greater than 0.5 mm near the bedrock surface. It is thought that at present, these cracks do not pose a serious problem on dam safety because they are discontinuous, but they need to be monitored (the areas encircled by a green line in Fig. 14).

• Vertical cracks

There are more or less continuous vertical cracks in the central region of the dam above the boundary with the bedrock and below a level roughly corresponding to two-thirds of the dam height. Most of the cracks have a width of 0.5 mm or less, but there are also a very small number of cracks having a width greater than 0.5 mm. These cracks need to be monitored (the area encircled by a blue line in Fig. 14).

Fig. 14
Distribution of more or less continuous cracks
Distribution de plus ou moins fissures continues

5. CONCLUSION

As an auxiliary means of visual inspection for cracks of the downstream face of an arch dam, a new video-based crack observation system has been developed. Equipped with a precision video camera with a telephoto lens, the system is capable of capturing images of the entire dam face under computer control within a short period of time, automatically transforming and joining recorded images and efficiently generating highly accurate crack maps showing the location, length and with of each crack.

The newly developed system was field-tested at an arch dam. In the field test, the system made it possible to clearly observe cracks in the regions that could not be observed by conventional inspection methods. Most of those cracks are thought to be due to drying shrinkage or thermal stress because many of those cracks are very small and mostly isolated and because there is no water seeping out of cracks.

Since, however, there are some more or less continuous inclined cracks in the lower parts of the right- and left-bank regions of the dam and there are also more or less continuous cracks in the lower part of the central region, monitoring needs to be continued on a continual basis. Because crack maps indicate crack coordinates, crack growth detected through two or more observations can be clearly expressed numerically. The newly developed system, therefore, is thought to be useful as an aid in visual observation conducted as part of a periodic inspection or a special inspection of a dam.