Inspection of construction joints in the concrete dam body by the impact elastic wave method

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ABSTRACT

The deterioration of the horizontal construction joints, which may affect the stability of the dam body is one of the phenomena of the aging concrete dams. The inspection by boring survey has been used to verify the state of the construction joints in the dam body. However, there are some problems in taking boring survey because it is costly, it needs to destroy even a very small portion of the dam body, and it can just check the spots, not the area. Therefore, the study was made on the non-destructive survey method to use the reflective wave of the elastic wave input by the impact, this method was applied for the survey of dam body of which the horizontal construction joints might be deteriorated. The following points were revealed: Estimation of the state of the construction joints by this method coincided with that from the boring survey from a practical standpoint.; This method enabled us to grasp the deteriorated construction joint area in the concrete dam body.; Additionally, proper set-up of the strength of sound portion and deteriorated portion of the construction joints enabled us to judge the safety of the dam body.

1. INTRODUCTION

In order to exploit limited social infrastructure, it is necessary to extend the life of existing facilities through conducting appropriate maintenance, and there is no exception in dams. Constant assessment of their state and implementing necessary corrective measures are essential.

Leakage on the downstream face of the concrete dam body is an occasional phenomenon observed on aged concrete dams. Leakage occurs mainly through horizontal joints due to the degradation of water stop plates installed on the joints and their periphery, as well as through the horizontal construction joint. In the former case, water storage performance becomes degraded but the stability of the dam body is rarely affected. However, the latter case suggests loosening of the joints to the degree that water can leak through.

Recognizing the range of the deterioration that can occur with a horizontal construction joint is important for evaluating the stability and durability of a dam body. A boring survey is typically conducted to check the state of the joint face. However, a number of issues also exist such as high cost, damage inflicted to the dam body (albeit minor), and the fact that it is a single point inspection. This method alone is thus not sufficient for investigating the total extent of degradation present.

This paper focuses on a technology for non-destructive inspection that utilizes the reflection of an elastic wave and summarizes the results of a review of the method for applying this technology to the survey of a dam body in order to estimate the range of deterioration present in a horizontal construction joint surface.

2. SURVEY USING THE IMPACT ELASTIC WAVE METHOD

2.1 Target Dam

The survey target dam is a concrete gravity dam with a height of 42 m and a crest length of 138 m constructed 41 years ago. Figure 1. shows the downstream face with some leakage.

Figure 1. The target dam

2.2 Detection of Damage Using the Impact Elastic Wave Method

The elastic wave that arises from an impact is able to penetrate deep positions, enabling analysis of these areas; however, waves with frequencies of 2 to 4 kHz or lower, which are generally used in the impact elastic wave method, pass through cracks as small as several mm without being reflected, thus leaving them undetected. This is because the propagating characteristics of the wave on the discontinuous plane change depending on the combination of the wave frequency, the dynamic rigidity and width of the discontinuous plane; while the frequencies of the passing and reflecting waves are determined by the width of the discontinuous plane. Therefore, in order to detect minute damage several mm wide caused by loosening and separation of the horizontal construction joint, the use of higher frequency waves is required. In order to check for minor damage in deep positions, this survey utilized AURIS (non-destructive exploration system)(Advanced Construction Technology Center 1997), which can detect cracks with an opening width as small as 0.3 mm by extracting and analyzing the high-frequency components of the reflected waves. The high-frequency impact elastic wave survey using AURIS has been widely applied when surveying pile lengths and cracks in existing piles, and the depth of embedment of bridge piers. (Nagai et al. 2013, Shiotsuki & Son 1998)

This system can detect microscopic damage by measuring the high-frequency components of the reflected waves as described below.

- For an impact wave oscillator (trigger), a high-hardness steel hammer was used. Its output contains many high-frequency components.
- For an impact wave receiver (detector), a piezoelectric sensor (AE sensor) with a high resonance frequency was used to detect certain high-frequency components.
- The output from the piezoelectric sensor passes through a high-pass filter, which extracts a certain range of high-frequency components that are most significantly reflected by cracks.

Figure 2. shows the principle of the survey.

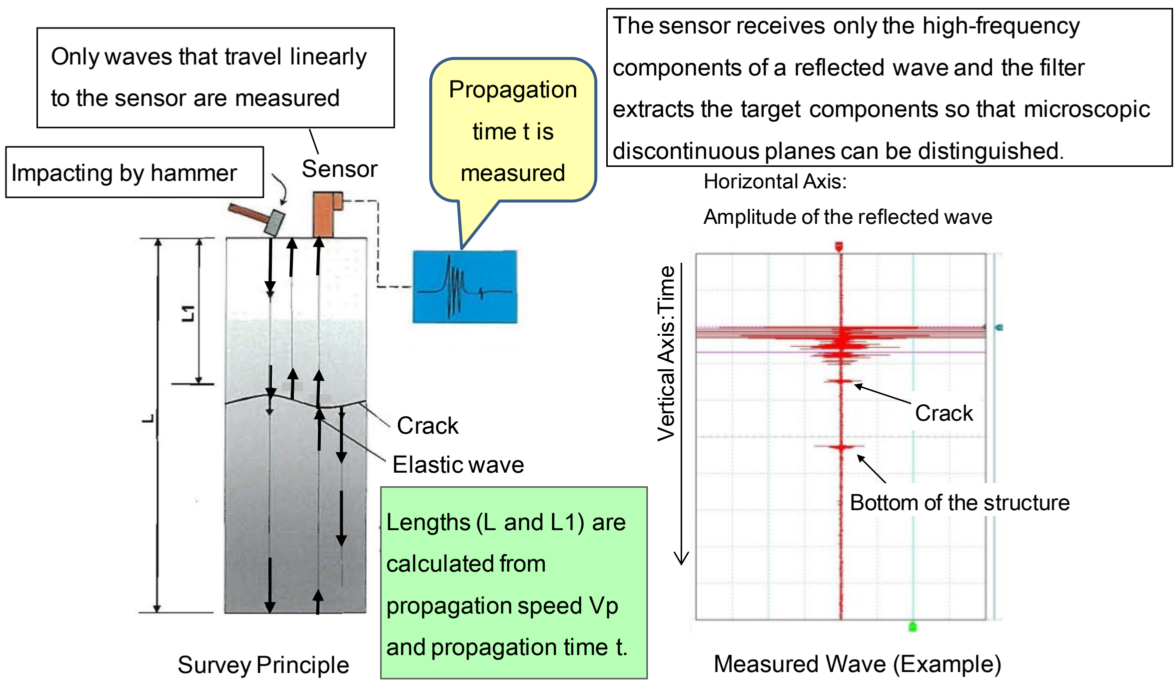


Figure 2. Principle of the Impact Elastic Wave Method

In this survey, the impact points and detection points are arranged in a grid pattern (with a frame of 2 m along the axis of the dam by 1m in the upward and downward flow directions) on the crown of the dam body and the overflow crest. The impact point is then struck with the hammer. The elastic wave, which is reflected by the bottom of the dam body, isolated construction joint, etc., is detected by the sensor installed near the impact point. With this arrangement, it is possible to investigate the state of the construction joint part inside the dam body just below each measuring point on the crown. The grid spacing (measuring interval) was set based on the fact that the probing limit of AURIS (non-destructive exploration system) is approximately 1 to 2 m from the measuring point.

The target, Dam A, has a height of 42 m. It is a small-to-middle size concrete gravity dam. It has a large concrete skeleton; therefore, a large amount of energy is required to generate elastic waves that travel from the crown to the lower levels of the dam body. If the level of the impact energy is not properly set, the reflected wave is lost in noise and the information on the reflected wave near the impact point (on the crown) cannot be clearly detected. To prevent this, based on the distance from the target region of the construction joint, an appropriate amount of impact energy was chosen from three primary levels: a high height level, a middle height level, and a low height level. In this way, it is possible to obtain information on the entire dam body.

Figure 3. shows a photo in which an impact is applied to an impact point on the dam crown followed by measurement of the reflected wave. Figure 4. schematically shows the relative positions of the impact points on the dam crown, horizontal construction joint for which the state will be estimated, and the state estimation points. An impact is applied at each point on the crown and the reflection wave is detected, providing information from the point on the joint faces just below the impact point.

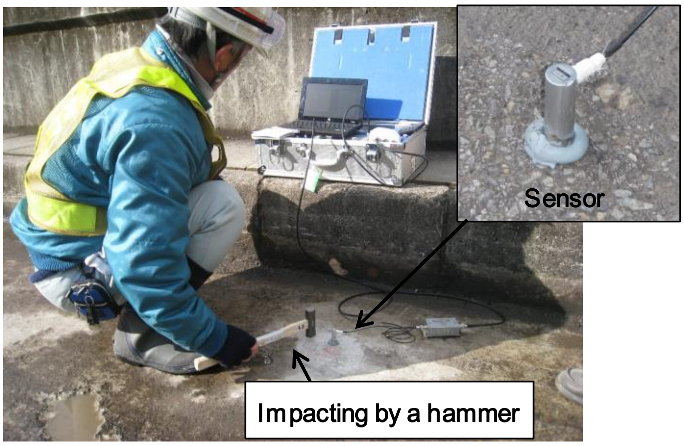


Figure 3. Measurement on the dam crest

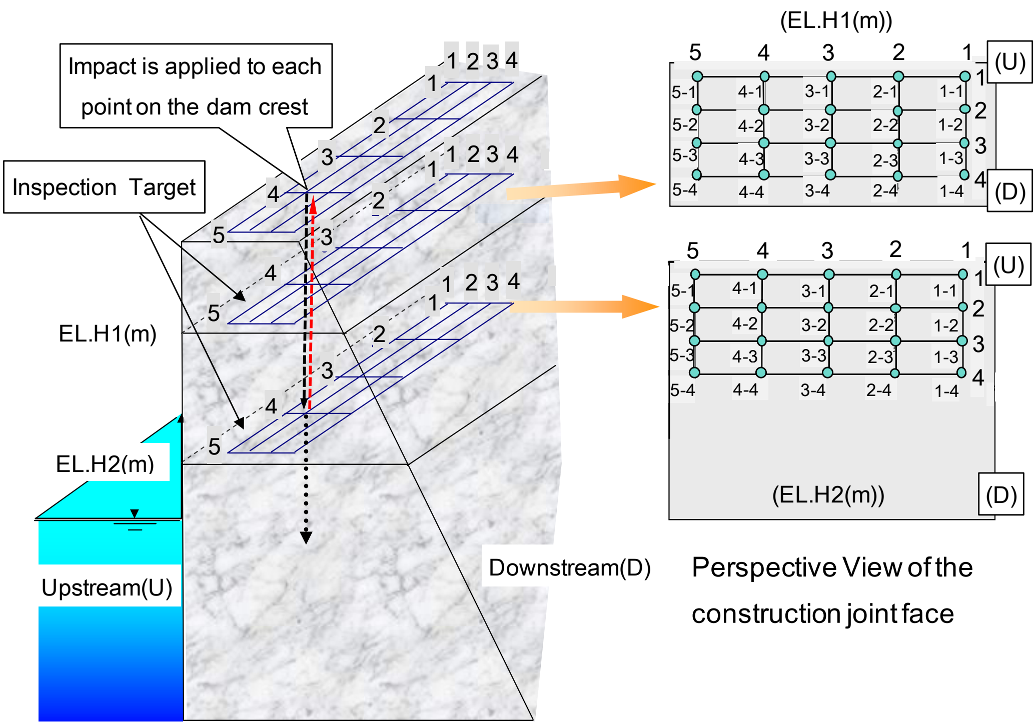


Figure 4. Detection of Horizontal Construction Joints by the Impact Elastic Wave Method (IEWM)

2.3 Categorizing the Measured Waveforms into Patterns

Figure 5. shows IEWM and measured waveform patterns. The measured wave, with attention focused on a certain depth, i.e. the depth to the construction joint, can be classified into three patterns as shown in figure 5.: Pattern A, in which the wave was not reflected at the assumed depth but mostly passed through at that level (a reflection was observed at a deeper level); Pattern B, in which the wave was reflected at the assumed depth but which also partly passed through at that level (another reflection was observed at a deeper level); and Pattern C in which the wave experienced a definite reflection at the assumed depth (no reflections were noted at deeper levels). Pattern A is estimated to indicate a state in which no degradation such as cracks exists at the assumed depth that reflects the elastic wave. On the other hand, Pattern C suggests the occurrence of degradation including cracks that do not carry the wave. Pattern B shows the presence of sections of degradation, which reflect the elastic wave, as well as other sections that transmit the wave.

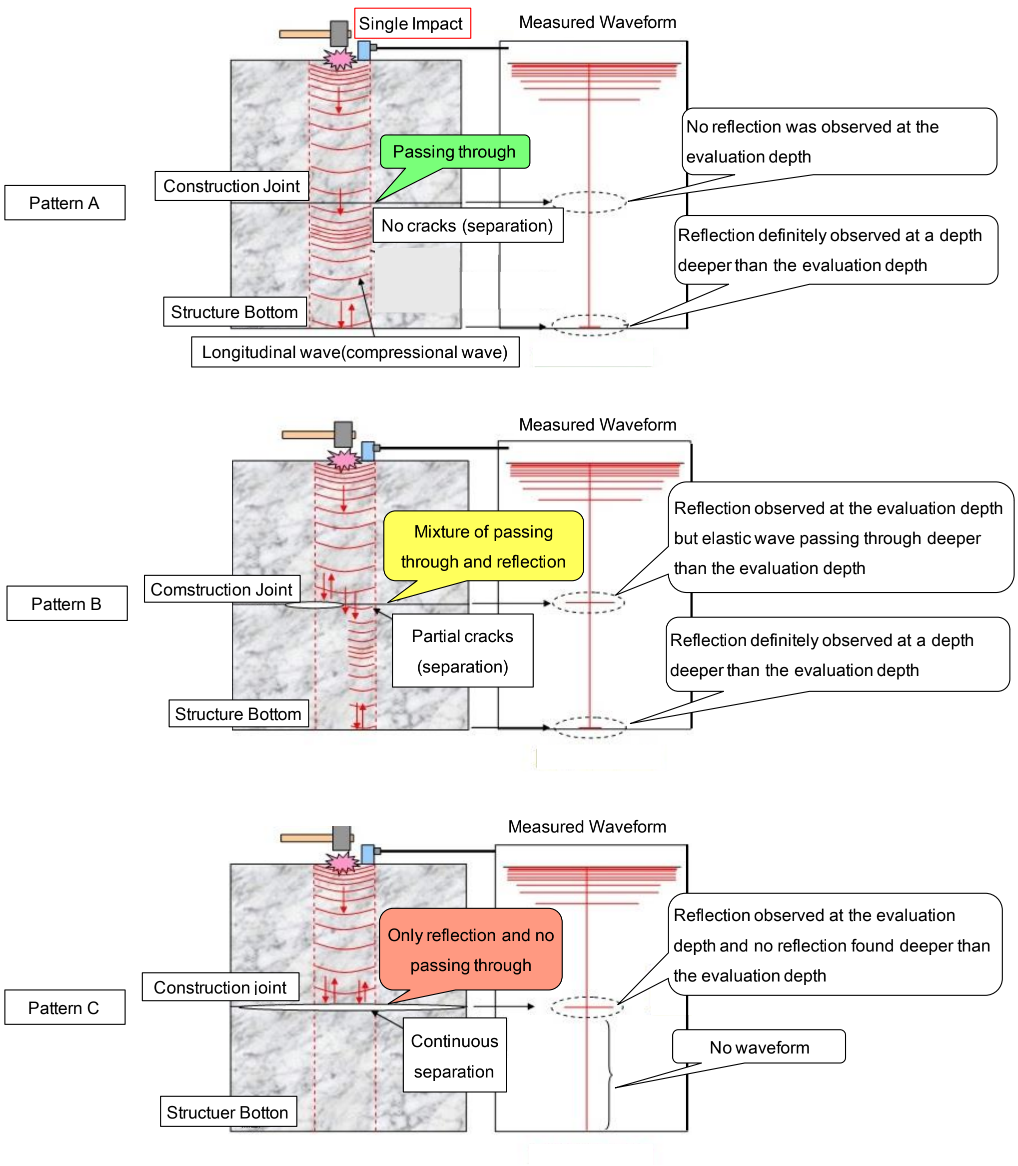


Figure 5. Measured Waveform Patterns

It is believed that the measurements using IEWM have high directivity, which provides information from a limited area on the construction joint around and directly below each impact point. However, due to the non-uniformity of the concrete, the propagation path of the elastic wave varies with each impact. In addition, in the case of microscopic cracks, the concrete is not completely separated into two surfaces, resulting in partial propagation of the wave, which is why several measurements taken at the same state estimation point do not provide the same waveform pattern. Because of this, ten or more waveforms were collected at each state estimation point and the state of each point was then categorized based on the percentage of occurrence of each waveform pattern.

3. SURVEY RESULTS

3.1 Associating Measurement Results with the State of the Construction Joint

To associate measurement results using IEWM with the state of the construction joint of the dam body, results from a boring survey that had previously been conducted and results from IEWM were compared.

Separation degree can be graded by the area of separation or the separation distance (opening width). In general, it is estimated that the greater the separation distance, the larger the area of separation is. Therefore, separation degree was determined to be categorized into four ranges.

Table 1. schematically indicates the state of the construction joint around a survey point analyzed by IEWM. The rates of Pattern A, B and C on the construction joint obtained with IEWM are determined by the state of the target construction joint. Therefore, based on the results of the impact elastic wave method of the 62 points on the construction joint for which the actual state had been confirmed in the boring survey, an optimal association index for estimating the type of construction joint (I, II, III, or IV) from the rate of each pattern was determined. Table 2. shows the relevancy indices for estimation of the state of construction joint from the results of measurements using IEWM.

Table 1. Assumed State of the Construction Joint around a Measuring Point

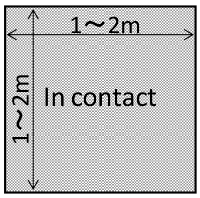
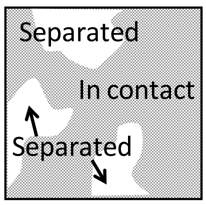
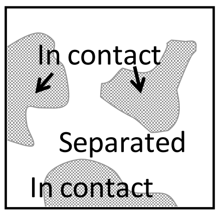
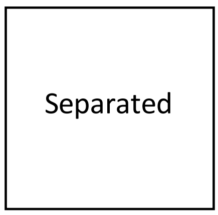
Category of the State of the Construction Joint	Assumed State of the Construction Joint around a Measuring Point	
Type I		・ There is no separation on the construction joint, or separation has been completely sealed with filling etc., leaving no gaps. ・ The waveform obtained with IEWM is classified into Pattern A.
Type II		・ The major parts of the construction joint are the same as Type I, but the face is partly separated, which generates gaps. ・ The waveform obtained with IEWM is classified into Pattern B.
Type III		・ Parts of the construction joint are the same as Type I, but the rest is separated, which generates gaps. ・ The waveform obtained with IEWM is classified into Pattern B.
Type IV		・ Major parts of the construction joint are separated, which generates continuous gaps. ・ The waveform obtained with IEWM is classified into Pattern C.

Table 2. Relevancy Indices for Estimation of the State of Construction Joint from the Results of Measurements Using IEWM

Category of the State of the Construction Joint	Rate of Waveform Patterns
Type I	80% < A and C = 0%
Type II	(1) 0 < A ≤ 80% and C = 0%, or (2) 0 < C ≤ 20%
Type III	(1) 20 < C ≤ 80%, or (2) 0 < A ≤ 20% and 80% ≤ C
Type IV	A = 0% and 80% ≤ C

3.2 Estimation of Horizontal Construction Joint from Measurement Results

Using the rate of each waveform pattern of the target construction joint obtained from measurements based on the impact elastic wave method, and the relevancy indices for estimating the state of construction joints as shown in Table 2., it is possible to estimate the state of each point on the grid regarding the target faces. For a total of 35 horizontal construction joints in which the occurrence of degradation was considered, including the conformation of leakage from the downstream side at Dam A, the state was estimated as follows.

- The rate of each waveform pattern obtained from the impact elastic wave measurement of each point on each construction joint is applied to the indices for estimating the state of the construction joints.
- Conducting estimation of the state on all measuring points on the construction joints provides information on the points on the grid pattern. As described earlier, the impact elastic wave system used in this survey measures the state of the area 1 to 2 m around each measuring point. Therefore, as Figure 6. shows, the surface state of the horizontal construction joint was estimated while considering the state of the neighboring points on the grid. The pitch of the gird was 2 m along the axis of the dam and 1m in the upstream – downstream direction, which were nearly consistent with the detection range of the measurement system. Thus, the measurement covered the entire grid. A grid pitch set to 2 m or more, for example, would have left unexplored areas, which would have lowered the accuracy of the estimation.

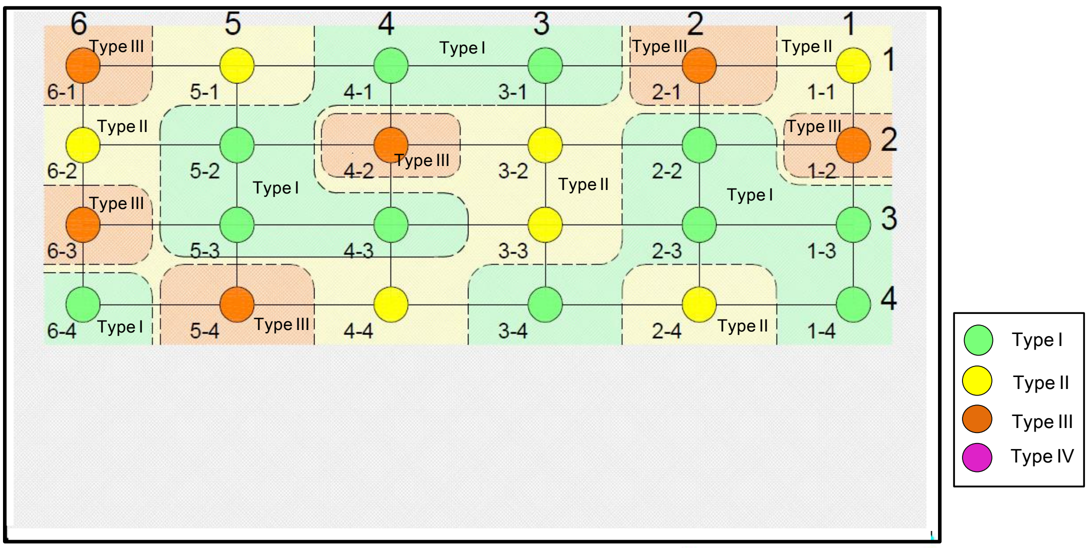


Figure 6. Sample Estimation of the State of a Horizontal Construction Joint

4. EXPLOITATION OF THE SURVEY RESULT

4.1 Quantitative Evaluation of the State of Construction Joints

By calculating the areal rate from the distribution of each type on the horizontal construction joint using the method described in the previous section, it is possible to quantitatively indicate the state of each construction joint. Table 3. shows the areal rate of each state type, which was obtained by calculating the area of each type indicated in Figure 6. using the area calculation function of the computer-aided design (CAD) software.

Based on the areal rates, the state of each horizontal construction joint can be obtained quantitatively by defining a characteristic value for each state type.

Table 3. Sample Calculation of the Areal Rate for Each Type Regarding the State of Horizontal Construction Joints

State Type	Type I	Type II	Type III	Type IV
Rate	44.1%	35.2%	20.6%	0.0%

4.2 Applications for Evaluation of the Soundness of the Dam Body

4.2.1 Measures against leakage from a concrete dam body

Identifying the route of leakage from the downstream side contributes to selecting an optimal method for preventing leakage and its reasonable implementation. Therefore, when considering measures to implement against leakage from the downstream side of the dam body, this method is effective for obtaining a distribution of the areas of degradation on the horizontal construction joints that can serve as leakage paths.

4.2.2 Reviewing the stability of a concrete dam body

When the horizontal construction joints of a concrete dam body become degraded resulting in looseness and separation, water penetrates into the joints, which increases the uplift on the upper part of the dam body above the horizontal construction joints, causing a decrease in the stability that serves to prevent overturning and shearing, which is one of the factors that guarantees the stability of a concrete dam body. In addition, the degradation of horizontal construction joints leads to a reduction in their shearing strength, which is followed by a decrease in resistance against shearing, resulting in a loss of stability that prevents shearing of the dam body. When reviewing the stability of the dam body, it is necessary to clarify the distribution of each state type and its areal rate on the construction joints.

The above information is obtained by conducting a survey of the construction joints of a dam body using the impact elastic wave method. It then becomes possible to analyze the stability of the dam body when the construction joints become degraded by clarifying the degree of the effects of shearing strength and uplift for each state type, which helps when reviewing the soundness of the dam body.

5. CONCLUSION

Results of the foregoing applications demonstrate that IEWM can reveal a range of degradation with regard to the horizontal construction joint faces of a concrete dam body. Although this survey method is still under development, it is expected that it will be an effective method for quantitative evaluation of the state of horizontal joint and utilization to review the soundness of concrete dam body.

6. REFERENCES

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