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INNOVATIVE TECHNOLOGIES FOR DAMS AND RESERVOIRS TOWARD THE FUTURE GENERATIONS

Investigation and Repair on Deteriorated Transverse joint of Kasabori Dam

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ABSTRACT:
Kasabori dam is a concrete gravity dam with height of 74.5m completed in 1964 by Niigata prefectural government in a snowy region, for the purposes of flood control and hydropower. It was redeveloped in 1973-79 and again in 2011-17 to upgrade its flood control function. The present work, which started in 2014, includes heightening the dam by 4m, placing concrete on its downstream surface to increase its thickness by 2m, renewing its two gates, and extending its spillway.
However, a visual inspection confirmed a serious increase of water leakage around the J2 transverse joint, and the extension of cracks along J2 since the first repair in 1973-79. Thus, before the main work, repair work started in 2014 and, cutting down around J2 by line drilling was performed after lowering the reservoir level. After water-stop installation and steel-bar reinforcement, the concrete was placed, and the J2 repair work was finished by June 2015. Experientially, there were some difficulties coping with the transverse joint trouble (Kawasaki, H., et al. 2014). In this paper, we introduce the investigation process and the repair work on the traverse joint, and try to explain the mechanism of deterioration by earthquakes and heavy freezing-thawing.

Keywords: Transverse joint, Leakage, Crack, Cutting face, Repair

1. OUTLINE

Kasabori dam is a concrete gravity dam with height of 74.5m completed in 1964 where is in mid of Niigata prefecture, for the purposes of flood control and hydropower. Since flood damage continued, the first redevelopment project was carried out from 1973 to 1979 to upgrade the flood control function. Its main works were the installation of one more crest gate and a spillway. In addition, the J2 transverse joint was repaired to decrease its water leakage. Figs. 1 and 2 show their situation.

The present redevelopment project was started after the serious flood damage by heavy rain in July 2011. The Kasabori dam project is intended to ensure its flood control function by increasing the dam height by 4m, placing concrete on the downstream surface to increase its thickness by 2m, renewing two gates, and extending its spillway (Figs. 3~6). The main work started in 2014, and the project is due to continue until 2017.

Repair work started in 2014, and cutting down around J2 by line drilling was performed after lowering the reservoir level. To cut and remove the area impacted by the crack around J2, the concrete cut volume was amounted about 50m^3, which is a big-scale cutting. Then, after installing the PVC water-stop, the reinforcing bar, and joint bar to unify the old and new body (Fig. 7), the new concrete was placed. And the J2 repair work was finished by June, 2015. At the same time, the grouting under J2 was carried out to reduce permeability and fill the voids under the dam base.

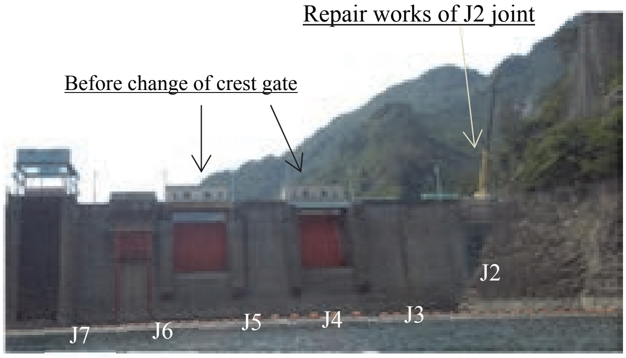


Figure 1. Upstream view of Kasabori dam on 2015.5.28

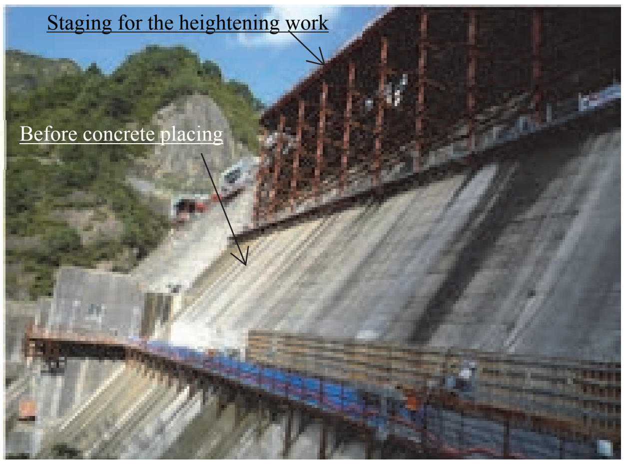


Figure 2. Kasabori dam under construction on 2015.10.05

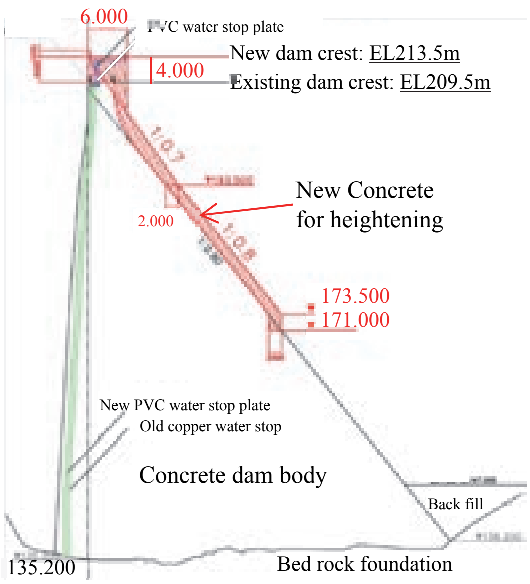


Figure 3. Cross-section of Block No.4 (Non-overflow section)

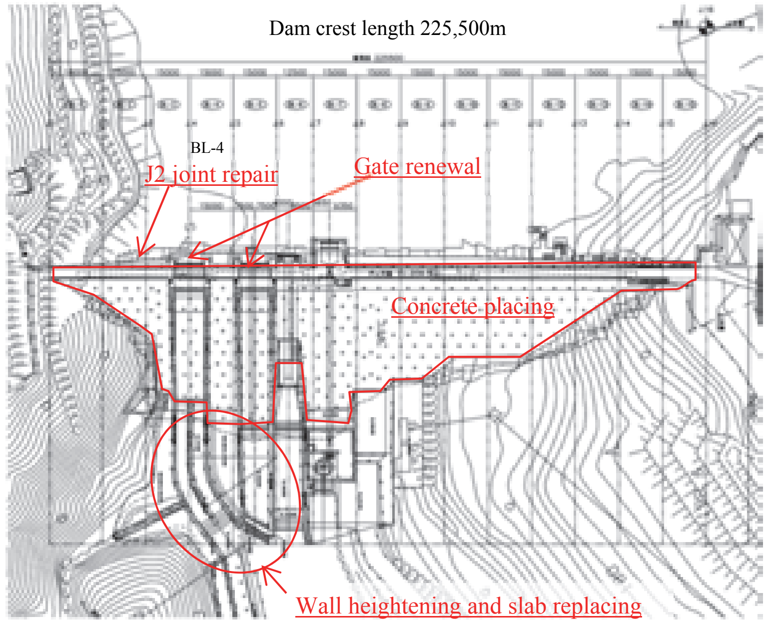


Figure 4. Ground plan of Kasabori dam

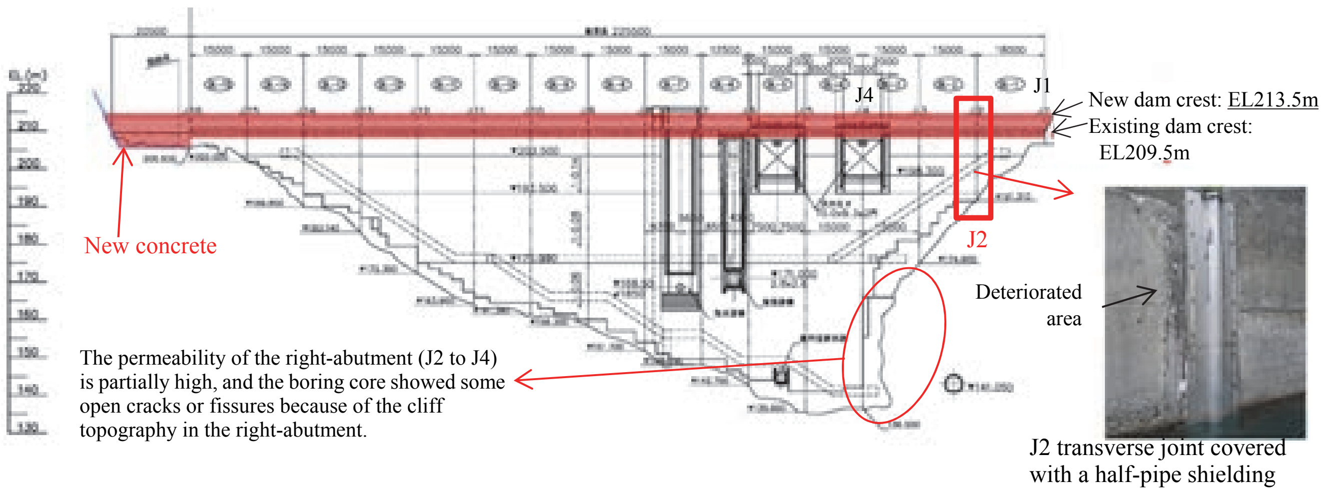


Figure 5. Upstream view of Kasabori dam (meshed zone shows the concrete placing zone)

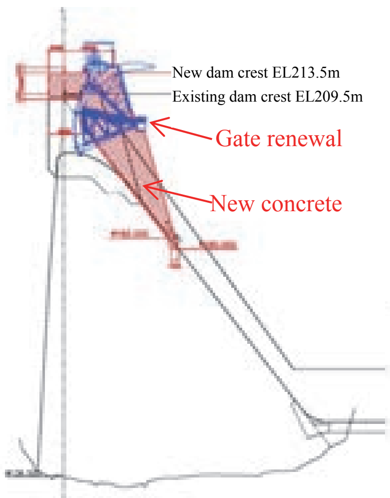


Figure 6. Cross-section of Block No.5 (overflow section)

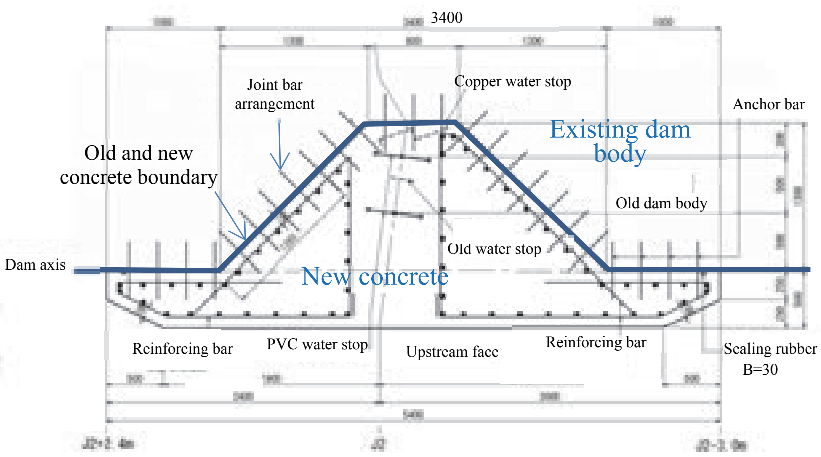


Figure 7. Repair plan of J2 transverse joint

2. WATER-PASSAGEWAY INVESTIGATION

Visual integrity investigations were conducted in 2012 and 2013 in advance of the redevelopment work. The results confirmed that on the surface of the dam body and its inspection gallery, deterioration such as water leakage, joint opening, cracks, exfoliations, and surface erosions had severely progressed. Since the dam is located in a heavy snowfall region, these phenomena were judged to have been facilitated by frost damage. Above all, the biggest crack was extended vertically and downstream along the J2 transverse joint in the dam right-abutment.

The deterioration condition of J2 upstream face is shown in Fig. 8. Although the water stop work was carried out by installing half-pipe shielding of stainless steel during the first redevelopment (ended in 1979), at present, big cracks have extended to the left along the half-pipe shielding, which was the locations of the water passageways (Fig. 9).

In the downstream face of J2, water leakage at a maximum of 500 l/min was measured in April 2013 when the reservoir level rose. Then, coloured water was injected from the bore hole, confirming that the crack along J2 is the main water passageway. Moreover, a suction opening was found by an underwater diving search at the upstream face near J2, and a drilling and endoscope survey confirmed that the cracks on the upstream face originated at J2 with the inner part. Based on the above water-passageway survey at J2 and its adjacent blocks, the following three points were confirmed as a main water leakage route (See Fig. 10)

(1) When the reservoir level was about EL195.0m, the water leakage in the downstream was not confirmed.
(2) When the reservoir level was EL201.5-203.5m, the water exuded from the joint of EL194-196 m.
(3) When the reservoir level was EL204.5-206.5m, the water leaked from the joint of EL199.0m (See Fig. 11).

Eventually, it was estimated that the water passageway is mainly "Open crack along J2 over EL200m => Estimated crack line through the dam body in Fig. 9 => J2 joint and inspection gallery => the J2 downstream end between EL199~196m". Thus, it was decided to thoroughly cut and remove the deteriorated concrete around J2, and to reconstruct the transverse joint.

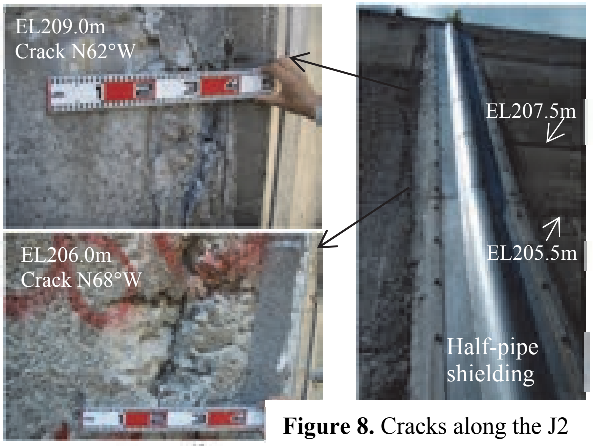


Figure 8. Cracks along the J2

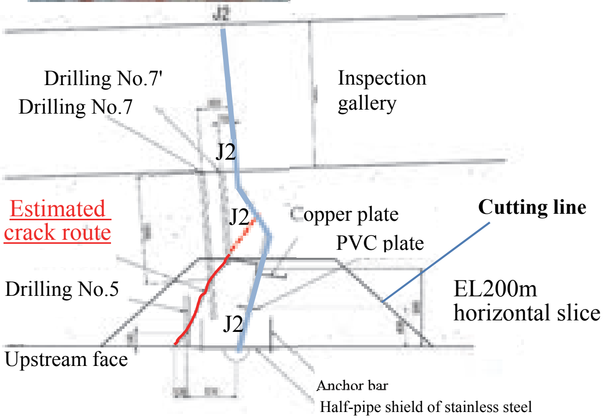


Figure 9. Crack survey plan by drilling near the J2 at EL200m

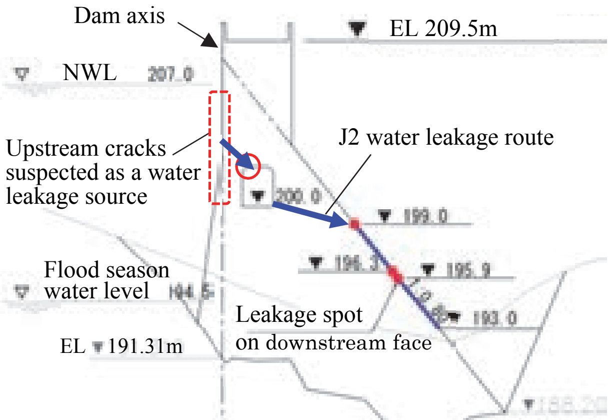


Figure 10. Cross-section of J2 and a water leakage route

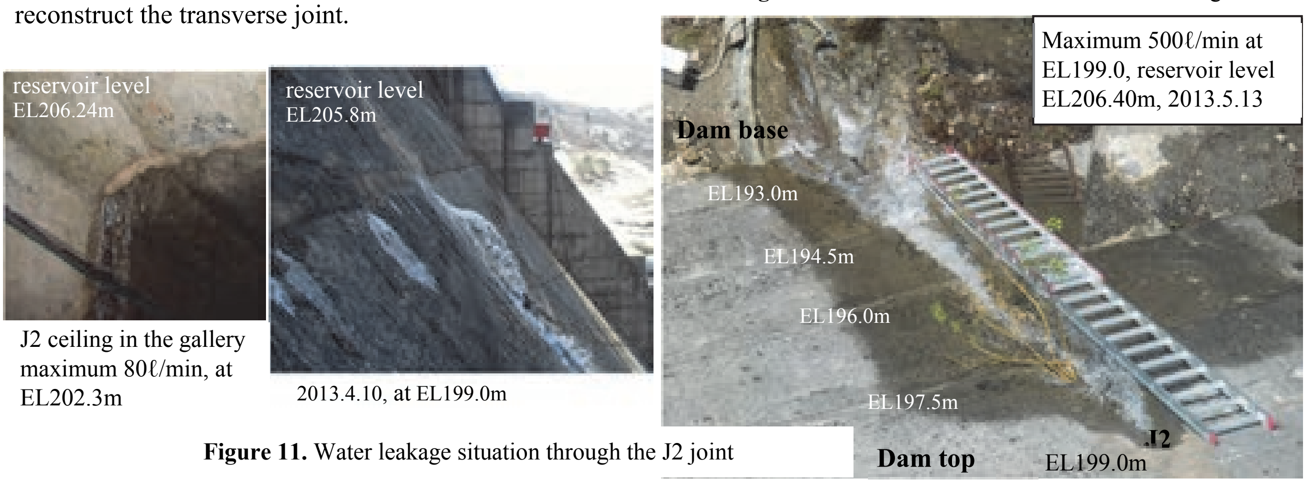


Figure 11. Water leakage situation through the J2 joint

3. REPAIR OF THE TRANSVERSE JOINT

Repair work was implemented by cutting and removing the dam concrete of the upstream face along the J2 transverse joint vertically to the dam bottom, and by reconstructing J2 by the next flood season (June, 2015). In addition, grouting work to improve the highly permeable zone of the bedrock under J2 and contiguity blocks was implemented.

These works were started in November, 2014 after lowering the reservoir water level, and ended in June, 2015. The cutting situation and extended cracks along J2 are shown in Fig. 12.

3.1 Cutting and face observation

The horizontal plane of the J2 cutting was determined to remove all the crack-influenced concrete. In the depth direction, it was cut to the surface of the bedrock in which the loosening was found. The cutting work was implemented for five months to March on 2014. On both sides of J2, cutting ranges were 3.5m x 1.3~ 0.9m in the horizontal plane, and it was 18m in height from the dam crest to the base rock (concrete cut volume: about 50m^3).

The concrete body was cut carefully after the outer edge cutting by line drilling and wire saw work. It was removed out every 0.75m in depth and cutting face was smoothed at 1~3m of depth. The distribution status of cracks was confirmed by the cutting face observation. Fig. 13 is the horizontal section showing the crack route through J2. The observation result is shown below.

3.1.1 Horizontal direction

The main crack passed through the left end of the copper water stop from inside J2, and it extended toward the upstream face. It is presumed that the water passageway occurred along the main crack. In the dam bottom, the main crack pierced through the concrete footing adjacent to the upstream side. It was shown that the crack progressed to the upstream side.

3.1.2 Vertical direction

The above main cracks continued downward along the left side of the half pipe shielding. The crack tended to incline towards the left (valley side) on the topographic slope. Further, the cracks were extended at the lower elevation, and reached the surface of the bedrock below the dam bottom. In addition, in the vertical cutting face, the crack shifted to the left side at the lower elevation.

3.1.3 The extension direction of the crack

It can be said that the main crack progressed upstream from downstream. It is assumed that the shearing that occurred in J2 initiated the crack, and extended it to the upstream face through the left end of the copper water stop. At the dam bottom, the main crack pierced the footing upstream, and below, it also extended to the surface of the bedrock.

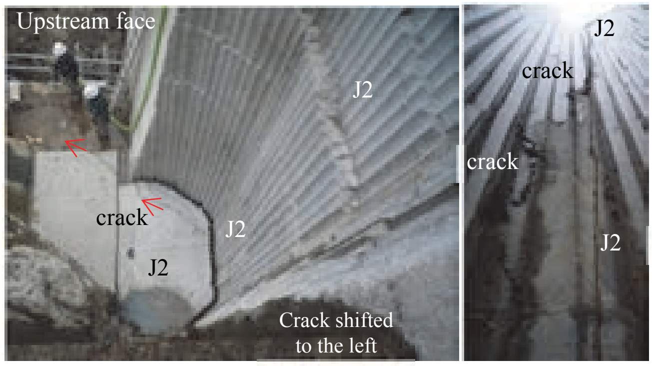


Figure 12. Cutting face and cracks at EL195.0m, 2015.2.26

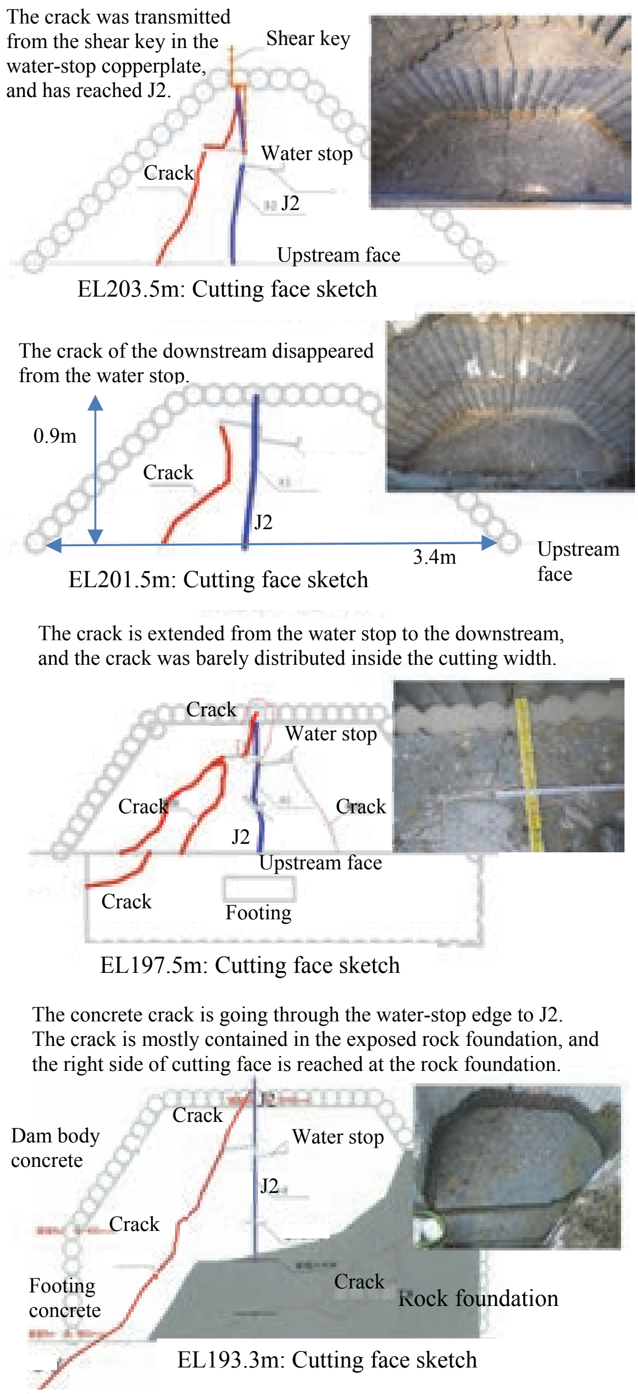


Figure 13. Cutting face observation along the J2

3.2 Reconstruction of the J2 transverse joint

A water stop and reinforcing bars were installed on the bedrock, and the concrete of the transverse joint and the footing was placed from March to June, 2015. The work process is described below (see Figs. 14 and 15).

3.2.1 Transporting the concrete

The concrete (ready mixed concrete) was transferred into the bucket from the concrete mixer truck, and was carried to the placing site by the rough terrain crane. Placing concrete was performed per 1.5m lift.

3.2.2 Adhesion of the existing and new concrete

In order to attain the unification of the existing and new concrete, while performing sufficient chipping of the existing dam concrete, the joint bars were arranged in the bonding plane. Moreover, reinforcing bars were arranged in the new concrete to increase its strength.

3.2.3 Water stop installation

Since a copper water stop might facilitate crack around the transverse joint, a flexible double vinyl chloride water stop was newly installed in the transverse joint.

3.2.4 Treatment of the crack section

In order to end the possibility of crack extension from inside the transverse joint, the crack section of the cut end was excavated in the shape of a trapezoid, and was filled up with highly adhesive repairing material (polymer cement).

3.3 Grouting to the rock foundation

A boring survey found some high permeability zones under the Blocks No.2 and No.3 near J2. So, grouting with fan-shaped layout was implemented from the inside of the inspection gallery to the bedrock to decrease the permeability. In addition, open cracks or fissures caused by the cliff topography were found in the boring cores of the bedrock, so grouting should be useful by reducing loosening. Some check borings will be conducted after the all grouting works in this year to confirm the permeability reduction and the void filling.

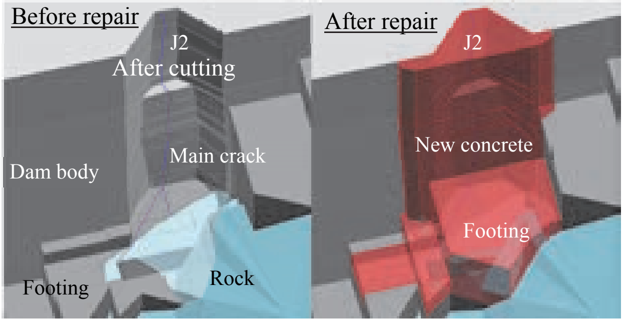


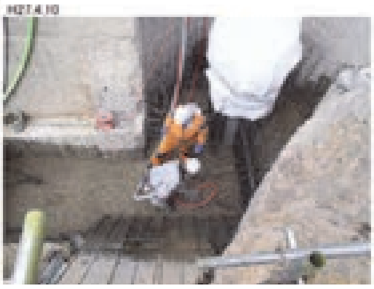
Figure 14. Image of the J2 joint repair

Deep cut in the rock foundation

Water-stop setting in the rock foundation

Crack break by the steel half pipe at EL193.3m

1st lift before concrete placing (EL193.3)



2nd lift before concrete placing (EL194.0)

3rd lift before concrete placing (EL194.75)

Joint bar setting to the old concrete body

4th lift before concrete placing (EL195.5)

4th lift after concrete placing (EL196.25)

Figure 15. Reconstruction works of the J2 joint

4. CRACK DEVELOPIMG MECHANISM

From the cutting face observation, it was confirmed the main crack from the J2 joint was extending to the valley side of the upstream face through the left end of the copper water stop. On the other hand, the Blocks No.2~ 4 of the dam body rides on the steep slope of the cliff, and the slope face inclines steeply to the valley and downstream. For this reason, the crack direction might correspond with the topographic incline.

The largest external force that induced the above crack was presumably the Niigata Earthquake in 1964 (June 16, 1964, see Fig. 16), which generated quite strong shaking with seismic intensity of 5 on the JMA (Japan Metrological Agency) scale in this vicinity. Although placing concrete at the Kasabori dam ended in October, 1964, the earthquake struck in the middle of high elevation concrete placing in June, 1964. Since the dam concrete, which had not reached sufficient strength suffered from the very strong ground motion, it is easy to imagine that many invisible cracks and other damages might have occurred inside the dam body near J2 and other transverse joints at that time.

After the dam completion, water leakage at J2 of a maximum of 500 l/minute was observed in 1976. Although the leakage was decreased greatly by the J2 repair in 1974-79, the total leakage of the inspection gallery increased again to 100~150 l/min after 2000.

On October 23, 2004, the Mid Niigata Earthquake struck the Kasabori dam, causing extremely strong shaking, which recorded 622 cm/s^2 at the dam crest. Then, while the leakage from the inspection gallery decreased sharply, the leakage from the J2 downstream face increased remarkably. It seems, therefore, that the cracks to the downstream face were enlarged and the water-passageway was changed, by this earthquake.

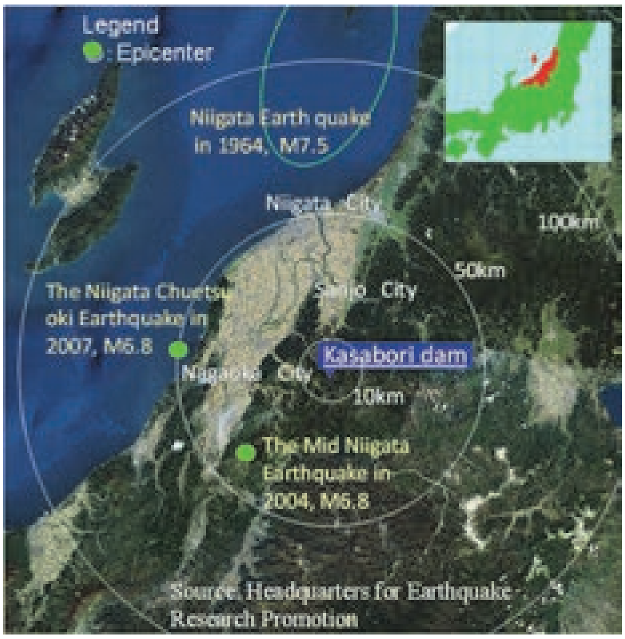


Figure 16. Kasabori dam and the past major earthquakes

5. CONCLUSION

The conclusions are described below.
(1) From the cutting face observation of J2 and around, it was confirmed that the main crack from J2 was extending to the valley side of the upstream face.

(2) All the cracks around J2 were confirmed to be inside the cutting width, and it was judged that the cracked area influenced by the J2 behaviour was mostly removed.

(3) Since the boundary of the old and new concrete is vertical, it was necessary to increase its adhesion. So, on the boundary face, chipping of old concrete, setting the joint bar to the adhesion face, and setting reinforcing bars to reinforce the new concrete, etc. were implemented.

(4) The copper water stop was removed and double flexible vinyl chloride water stops were installed. In addition, the opening crack around the back of the water stop was cut off deeply, and filled with polymer cement.

(5) High permeability zones with open cracks or fissures were found in the bedrock under the Block No.4 and NO.3 by the cliff topography. Thus, the grouting work was performed to reduce the permeability and loosening.

(6) The original cause of the leakage in the J2 joint was presumed to be the big impacts of the Niigata Earthquake in 1964, and the heavy freezing-thawing facilitated the concrete deterioration, and the Mid Niigata Earthquake in 2004 gave the damage around J2.

The following are future subjects to be checked.
a. Checking the effect of the dewatering works: During full impoundment in 2017, the water stop effect of the J2 repair will be confirmed.

b. J2 repair from the inspection gallery: The inspection gallery (near EL 201m) is very close (about 1m) to the cutting area. So, it is necessary to complete the water leakage repair from the inspection gallery after the check during impounding has been done.

Finally, the main work for dam heightening will starts in April, 2016. The concrete will be placed on the downstream face. Since the horizontal thickness of the new concrete is as thin as 2m, advanced countermeasures against temperature cracks are due to be performed.

ACKNOWLEDGEMENT
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