Technical solutions on concrete for Kasabori dam heightening

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ABSTRACT

Kasabori dam is a gravity-type concrete dam with height of 74.5m constructed in 1964 by Niigata Prefecture for the purpose of flood control, power generation, etc.. After a serious flood damage in 2011, the redevelopment project started to upgrade the flood control function by heightening the dam by 4 m. On the other hand, this project term was limited to seven years due to disaster restoration grant project, and the workable days of a year are largely restricted because of avoiding heavy snow season and flood season. So, the major challenge is how to complete the construction in a short period.

The project includes various works such as concrete placing on the downstream face and crest, renewal of two crest gates, improvement of the spillway and energy dissipater, repair of the transverse joint, and grouting to the dam foundation.

In this paper, we focus on the rational designing of dam heightening and the seismic safety evaluation, the crack control measures and unification of new and old concrete, and the speed up and facilitation of complicated work site by precast forms.

1. OUTLINE

Kasabori dam is a gravity-type concrete dam with height of 74.5m constructed in 1964 by Niigata Prefecture for the purpose of flood control, power generation, and water supply in the upstream region of the Ikarashi river of the Shinano river system, about 200 km North of Tokyo. Since flood damage in the downstream areas continued, the first redevelopment project was carried out from 1973 to 1979 to upgrade its flood control function. The main works were the addition of a crest gate and a spillway to increase its flood discharge and the repair of a water leakage joint.

In recent years, the Ikarashi river has continued to suffer serious flood damage, in 2004 and 2011. In 2011 in particular, flood damage caused by unprecedented torrential rain was designated as Wide area serious disaster, so a disaster restoration grant project for the Ikarashi river extending to FY 2017 (originally 2015) was adopted. The project consists of three parts, improvement of Ikarashi river channel, construction of retarding basins along Ikarashi river, and redevelopment of Kasabori dam to strengthen the flood control function by heightening the dam by 4m.

Though the dam redevelopment project normally needs over ten years, this grant project was limited to seven fiscal years including the year the disaster occurred. Also, there are restrictions on heightening an existing dam while operating its reservoir, and it is necessary to avoid major works in the flood season in order to control the floods. Moreover, since the dam is located in a heavy snow area, major work must not be executed in the winter months. Therefore, the major challenge of this project has been how to complete the construction in a short period of time while the project period and the feasible construction period of the year are largely restricted.

Under these conditions, the geological survey, facility review, operation plan, basic design, computer analyses, facility design, hydraulic model experiment, repair plan, and execution scheme were implemented from 2012. Then, on-site construction began in September 2014 with improvement of the spillway, and in 2015 the dam heightening and the gate renewal became full scale work. The project will be completed in March, 2018.

The Kasabori dam redevelopment consists of many parts as shown in Figures 1-3 (Author et al. 2016), and the project includes various works such as temporary construction (aggregate and concrete plant, yards and scaffolds), improvement of the spillway energy dissipater, concrete placing on the downstream surface and crest concrete, renewal of the two crest gates, reconstruction around the gates, repair of the transverse joints, grouting to the foundation, building of the management house, installation of the measuring systems, etc.. These works have been progressing as shown in Table 1. In this paper, we introduce the rational design of dam heightening, concrete crack reduction, and work facilitation at a complicated structural construction.

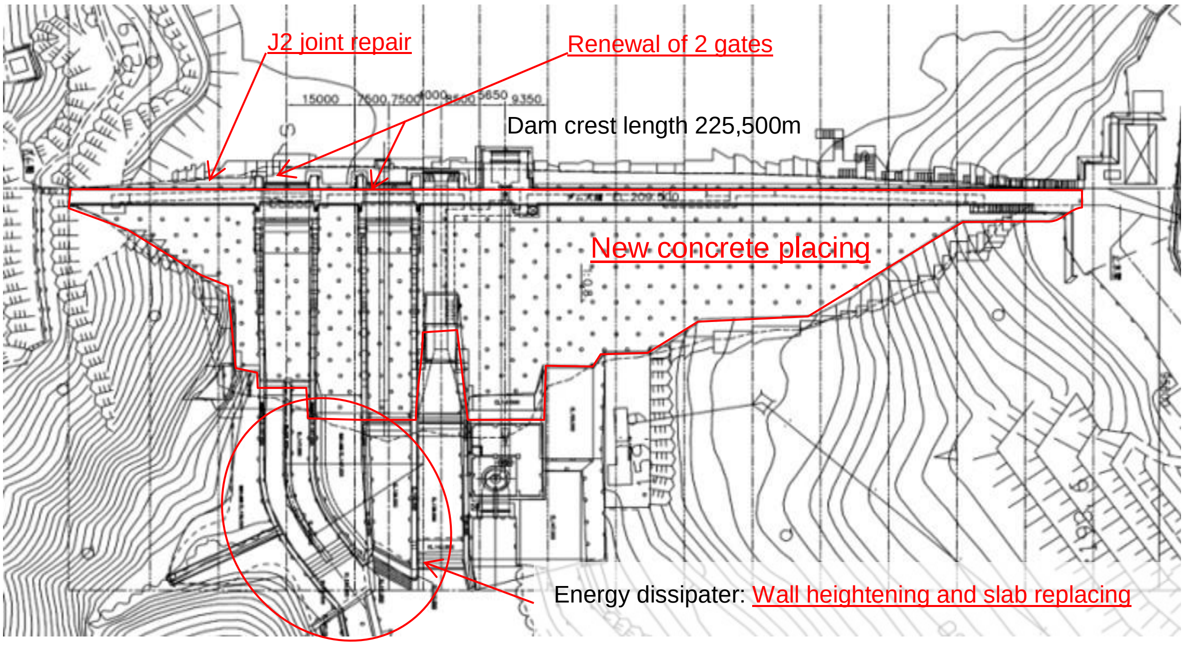

Figure 1. Ground plan of Kasabori dam

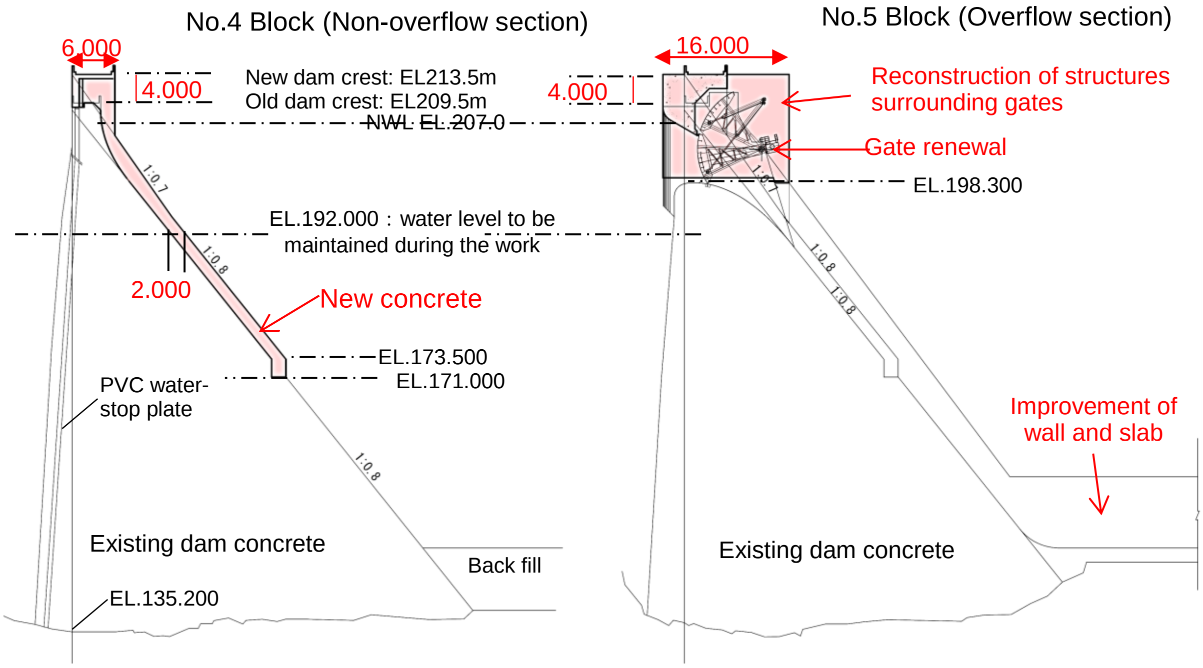

Figure 2. Cross-section of Kasabori dam

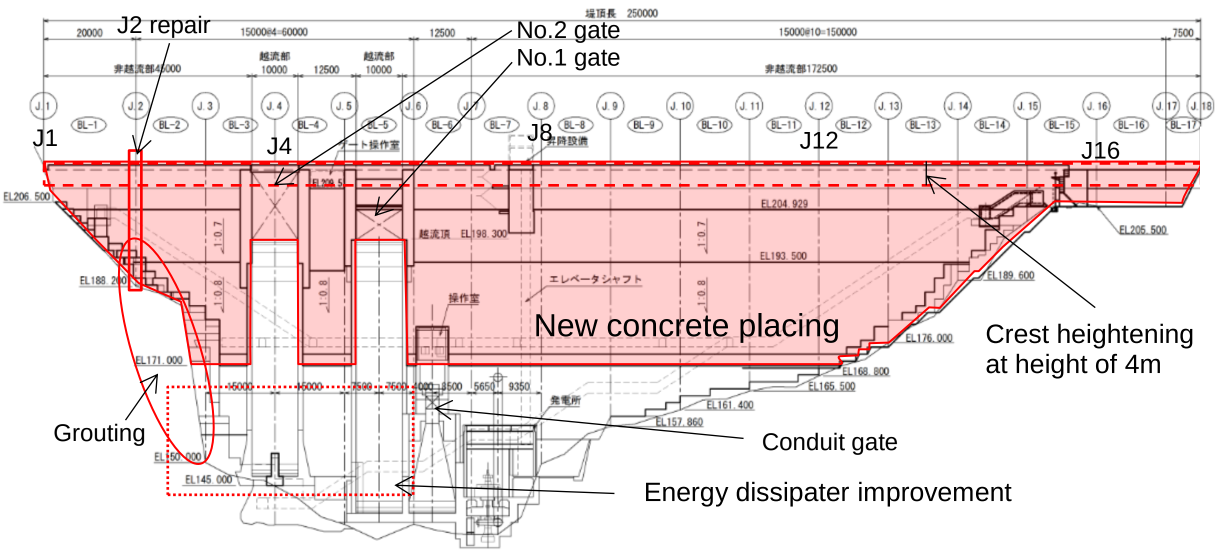

Figure 3. Downstream view of Kasabori dam

Table 1. Project Construction Schedule ■ : Flood period: from June 15, to September 30

Items of works	2014 April to March	2015 April to March	2016 April to March	2017 April to March
preparatory works	Temporary facilities	apron yards removal		crane removal
Foundation excavation: 5,129m³				
Concrete placing on the dam crest: 1,544m³				
Concrete placing on the downstream face :20,202m³		Lower part		higher part
Gate renewal: 2 gate manufacture and installation		No.1 gate	No.2 gate	
Reconstruction of relevant structures around gates		gatepost, curtain wall, crest, bridge		
Spillway and Energy dissipater improvement	wall heightening and slab replacing			
Grouting: Consolidation 1,141m, Curtain 7,102m		consolidation grouting	curtain grouting	
Water-stop work at J2 joint	cutting joint vertically and reconstruction			
Management house, control and measuring system		house / control system		control system
Impounding from EL.192m to 211m of water level				

2. PLANNING AND DESIGN OF THE DAM HEIGHTENING

2.1 Planning the reservoir storage of flood control capacity

In the Kasabori dam, although the normal water level (NWL) is EL. 207.0m, the reservoir level during the flood term (15 June~30 September) is limited to EL 194.5m. In addition, preparatory discharge just before a flood shall lower the reservoir level to utmost EL 192.0m. Without changing the above water level, the new reservoir plan is intended to ensure easier operation of the current flood control plan by securing an additional 1,800,000m^3 which equals the 20% of the present flood control capacity. In Japan, the flood control capacity is usually instructed to secure a surplus capacity of 20%.

Eventually, setting the surcharge water level (SWL, full water level in floods) to EL 211.0m which is 2.5m higher than now, secures the surcharge storage capacity of 2,900,000m^3 (now; 1,100,000m^3), and the total flood control capacity increases to 10,500,000m^3 by the preparatory discharge operation just before the flood. Moreover, adding the free board height 2.5m (now, 1.0m), the dam height at the crest becomes EL.213.5m, that is 4m higher than the present EL 209.5m.

2.2 Design of the heightening shape

The heightening shape of the dam body was decided by comparing the downstream surface gradient and the foot elevation of the new concrete at three water levels during the work, and calculating their stability by regarding its old and new concrete as a unified rigid dam body. Therefore, by lowering the water level during the works to EL.192.0m, it was possible to steepen the downstream slope to 1:0.70 (value in the existing dam: 1:0.8) and raise the heightening start point by 10m. We could reduce the new concrete volume in this way. Also, by lowering the water level to 192.0m during the works, water stop works like a cofferdam or waterway change are no longer necessary to set the two crest gates during the non-flood period, and the safety of the work during snow melt floods is enhanced.

The dam crest width was decided to 6m, which is 2m wider than now, considering workability such as a crane travel for gate installation. Concrete cutting of the dam body is necessary to increase 2m width, but the cutting is disadvantageous in terms of workability and economy. Therefore, we decided to widen the 2m by increasing the concrete placing part, minimizing the cutting of the dam body. The above design results is shown in Figure 2.

2.3 Design of the spillway and energy dissipater

A hydraulic model experiment of the spillway and energy dissipater to the increased water level was carried out in 2013. The experiment in the case of the design flood water level showed that the discharge flow amount should be reduced because the discharged flow condition from No. 1 gate was not stable by Interference with conduit flow. As a result, the total discharge capacity of 1,400m^3/s at the design flood water level was allocated 200 m^3/s to No.1 gate, 1000 m^3/s to No.2 gate, and 200 m^3/s to the conduit gate. The positions of the gates and the spillway are shown in Figure 3.

However, the discharged water concentrates on the left bank side, so structural strengthening of the lower spillway was designed by heightening the retaining wall, installing a flow separation wall, installing a side wall deflector (wave return), etc. In addition, according to the measurement of hydrodynamic pressure, flow velocity and water surface acting on the stream bed, it was clear that the flow velocity on the bed is too large, so vertical deflectors (end sills) were installed on the stream bed.

2.4 Renewal of gates and surrounding structures

The existing gate facilities consist of one conduit gate (B 2.80 m × H 2.30 m) and two crest gates (B 10.0 m × H 9.50 m + B 10.0 m × H 10.90 m). The following is a basic policy for the renewal.

- Crest gates: No.1 gate was renewed to an orifice gate (B 10.0m × H 6.70m). No.2 gate was renewed to an upper open type (B 10.0m × H 14.15m) since the gate height increased with the dam heightening. But, the lower ends of both gates were set at the same elevation as the existing overflow surface to use the existing waterway chute. Besides, the power systems were changed to hydraulic type (oil pressure).
- Conduit gate: Although the design water depth increased, the gate body, the hoist machine and the conduit could still be used. So, it was judged that they need not be changed, but that the operation equipment should be updated due to aging of about 50 years.

3. SEISMIC SAFETY EVALUATION

The Kasabori dam has been struck by large earthquakes twice, in 1964 and 2004. Though these did not clearly damage the dam, it is very important to confirm its resistance to large earthquakes. In addition, as the shape of the dam heightening, there is a 2.5m vertical rising at the foot elevation of new concrete. So, we feared that this discontinuous shape would concentrate stresses.

The level 2 earthquake motion almost equal to the Maximum Credible Earthquake was set, and seismic survivability was checked by calculating the local stress of dynamic analysis using the level 2 earthquake motion. As a result, although tension cracks occurred at the upstream toe, the cracks were not continuous in the upstream and downstream directions. Besides, it was confirmed that the results of analysis satisfied the two seismic safety conditions, which are no uncontrollable water discharge and repairable damages. The following is the analysis process.

3.1 Creation of level 2 earthquake motion

As the earthquake that can presumably most seriously affect the dam, the earthquake motion with the minimum necessary acceleration response spectrum was set after comparing past earthquakes, near seismic sources (inland types, inter-plate types). Furthermore, three waves observed at dams were selected as the original waveforms including Kasabori wave (Mid Niigata prefecture Earthquake in 2004). Level 2 earthquake ground motions (acceleration time history waveform) were created by stretching these waveforms to match the period and acceleration of the assumed earthquake.

3.2 Identification analysis and modelling of finite element method

Identification analysis was implemented to decide the physical property values, by the linear dynamic analysis of the two-dimensional FEM at the maximum cross section (No.4 Block, see Figure 4), using seismic records in the dam base and dam crest at the Mid Niigata prefecture Earthquake in 2004. As a result, damping constants were set by 5% in the dam body and rock foundation, and the elastic moduli were set by 20,000 MPa in internal concrete, 25,500 MPa in external & new concrete and 32,000 MPa in rock foundation. Poisson ratios were set by 0.2 in concrete and 0.3 in rock foundation. Tensile (compression) strengths were set by 1.8 MPa (18M Pa) in internal concrete and 3.0M Pa (30 MPa) in external & new concrete.

3.3 Dynamic analysis

Linear dynamic analysis was performed with the two dimensional FEM model at No.4 Block after heightening, using the three level 2 seismic ground motions. As a result, shear and compressive failure did not occur, but stress exceeding the tensile strength occurred at the upstream toe of the dam body and the possibility of tensile cracking increased. Next, as a more detailed analysis, the nonlinear dynamic analysis considering a damage process with tensile softening characteristics was carried out. As shown in Figure 4, although cracking developed until 15m inside from the upstream toe, the maximum tensile stress was lower than the tensile softening initiation stress in all the waveforms.

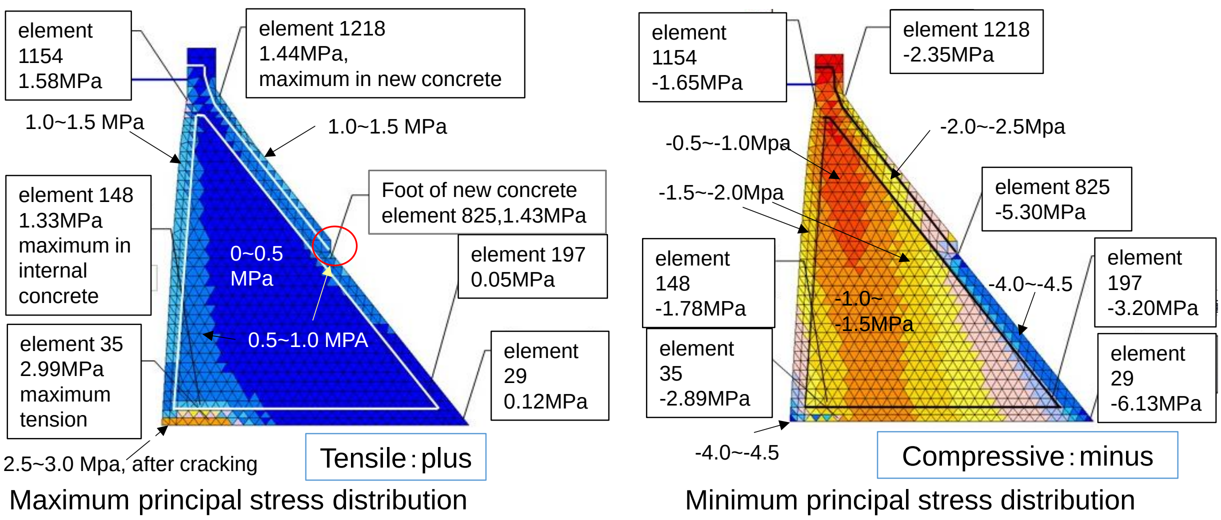

Figure 4. Maximum stress by Non-linear FEM (maximum values in all time, Kasabori wave)

At the foot of new concrete (see Figure 4), the maximum compressive stress was 5.30 MPa and the maximum tensile stress was 1.43 MPa. Although they were higher than values in the neighboring elements, they were lower than the compressive strength (30 MPa) and tensile strength (3.0 MPa).

4. SOLUTIONS FOR LESS-CRACKING AND UNIFICATION OF NEW AND OLD CONCRETE

In a case where new concrete is added to a downstream surface, the new concrete lift is thin and long. So, there are two factors on tempereature cracks, which are the internal restaraint by hydration heat of new concrete, and the external restraint by old concrete. Moreover, there are two type cracking, which are longitudinal cracking along dam axis direction, and transverse cracking along up- down direction.

4.1 Countermeasures against longitudinal cracks and temperature stress analysis

In the Kasabori dam heightening, since the new concrete is as thin as 1.56 m (horizontal width 2.0 m), the temperature cracking by the above restraint was feared. So, the adiabatic temperature rise formula was estimated by conducting the standard concrete specimen test, and other physical values for the analysis were decided by tests of new concrete and core sampling pieces. Then the stress distribution in the dam body was estimated by the temperature stress analysis by two dimensional FEM analysis.

After the computation for the case with no countermeasures against cracking, the maximum temperature strain in all elements of the old and new concrete was found to be 200 μ or more, and the probability of crack occurrence rose to almost 100%. Accordingly, several countermeasures such as "moderate-heat fly ash cement (30%mix), unit cement reduction 10 kg/m^3, improvement of the lift schedule, stop of summer concrete, thermal insulation curing of overwintering lift, etc." were adopted.

As the result of the case with countermeasures (see left of Figure 5), the maximum value of the temperature strain was improved to 119μ in new concrete (cracking index; 1.28, crack occurrence probability; about 20%, see Figure 6 right). Also, it was improved to 136μ in old concrete (cracking index; 1.07, crack occurrence probability; about 40%). The maximum value of the temperature strain appears around the foot elevation of new concrete, and this area is subject to external restraint by the existing dam body from two directions, which are the bottom and the slope face. So, tensile stress in the vertical direction is dominant (see center of Figure 5). Besides, in the old concrete, the maximum strain appears immediately above the overwintering lift where the concrete placing was stopped in the winter, and the influence of the contraction of new concrete below the wintering lift is large.

Eventually, since these high strain areas are limited to some narrow areas, we considered that it was possible to overcome this temperature problem by arranging reinforcing bars and joint bars in the new concrete (not reflected in the analysis, see right of Figure 5). In addition, the standard permissible strain is generally 100μ, but the elongation ability up to 130 to 200μ has been confirmed by past data on dam concrete. Thus, the possibility of harmful cracking was estimated to be considerably low, and the above values were expected to be within the allowable strain range.

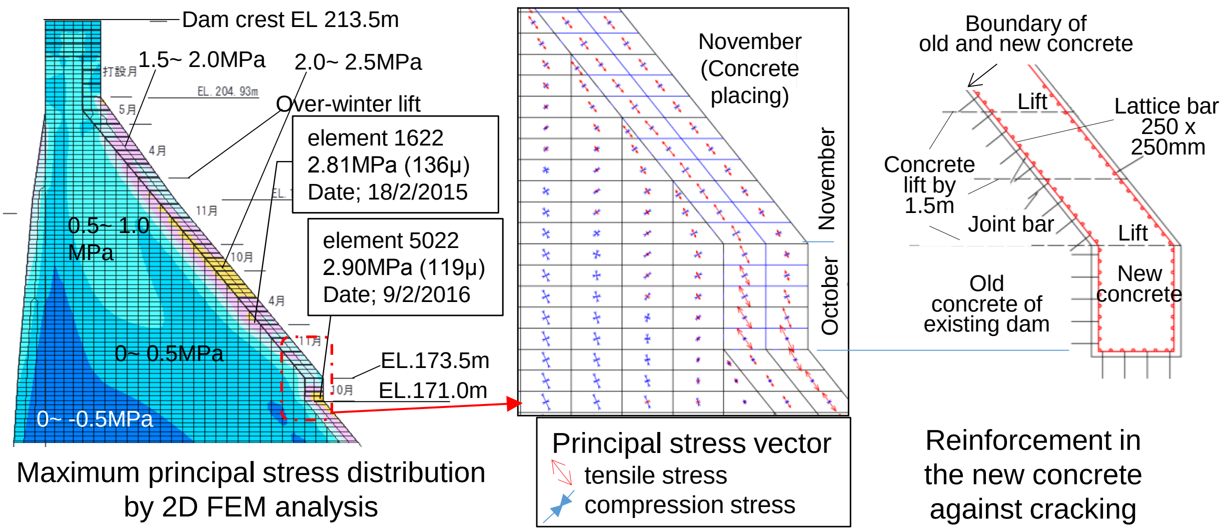

Figure 5. Maximum principal stress distribution after countermeasures

4.2 Countermeasures against transverse cracks and temperature stress analysis

The start of new concrete placing on the downstream surface was delayed from October to May when the temperature stress increased. Moreover, since the new concrete is long in the dam axis direction, there is a risk of transverse cracking by the external restraint. So, we reconsidered measures against cracking. After researching the past experiences of some concrete dam, it was judged that further countermeasures was necessary, and the block splitting in the transverse direction would be the most effective way to suppress transverse cracks, by shortening the longitudinal length.

Then, three-dimensional FEM analysis was carried out for the case where the block width was 15m, and the case where partitions were installed at intervals of 5m. As the result of analysis whose starting was set in May shown in Figure 6, it was confirmed that stresses and cracking indexes in the dam axis direction were greatly improved by transverse partitions. Especially, cracking indexes showed this effect more clearly. In detail, the minimum cracking index which appeared after block splitting was improved to 1.4 or more from 0.6-1.4, and it means the probability of crack occurrence was reduced to 0% from 15-100%. This big change occurred because the external restraints in the dam axial direction are reduced by shortening the restraint interval. Eventually, it was judged that a marked effect was expected by adding the transverse partitions, and the block splitting at 5m intervals was adopted to reduce tensile stresses of the dam axis direction in the new concrete.

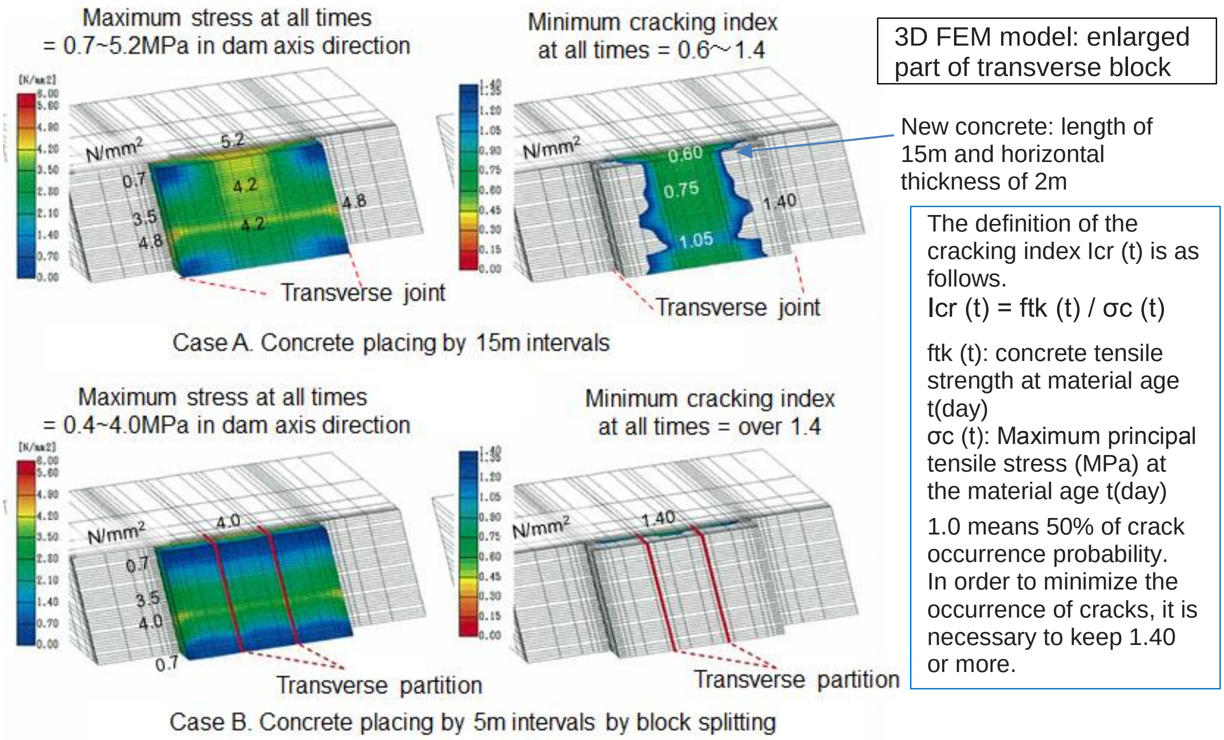

Figure 6. Maximum temperature stress and minimum cracking index by 3D FEM analysis

4.3 Concrete mixture proportion

Mixture proportions of three concrete types were adopted using fly-ash mixture (30%) and high performance admixtures; external use (downstream surface, see Table 2) and structural use (reinforcing bar section). In particular, since this area is frozen in winter, many cases of the indoor freeze-thaw tests were performed to concrete specimens with low W/C and high air ratio, then aggregates and mixture proportions with verified frost-resistance were selected.

Table 2. Concrete mixture proportion

Mixture proportion	Maximum size of aggregate	Slump value	Air ratio	Water cement ratio ; W/C	Unit content kg/m³					
					Water	Cement+ flyash	Fine aggregate	Course aggregate mm		
								80~40	40~20	20~5
External concrete	80mm	3.0± 1.0 cm	4.6±1 .0 %	40.5%	85	210	670	493	486	492

4.4 On-Site work for less cracking and unification of new and old concrete

Concrete placing on the downstream surface started in May 2015, but was stopped for 2 months from mid-July to mid-September due to the hot temperatures. Then, Concrete was placed from mid-September to mid-December. In 2017, concrete will be placed from May to July, and all concrete works will be finished. Below, we describe the technical features of each construction stage adopted to ensure smooth progress of the work accompanied by sustained high quality (Author et al. 2014).

4.4.1 Chipping of old concrete

In order to unify the old and new concrete, the deteriorated part of the existing surface concrete must be removed. As a result of testing four methods, water jet, spikey hammer, bit roller, punch cutter for on-site use, the water jet (pressure 200 MPa) which provides the highest ability was adopted (see Figure 7a). The chipping depth was set at the usual value of 3 to 5 cm, but the neutralization depth of the boring core collected from the dam body was a maximum of 5.5 mm.

4.4.2 Setting the transverse partition and reinforcing bars

In order to reduce the risk of cracking, vertical partition of iron plates were installed at intervals of 5 m between 15 m of a transverse joint interval (see Figures 7c, g), and the restraint length in the dam axis direction was reduced to one third. Additionally, the joint bars (D22mm, Deformed bar) were inserted into the old concrete to ensure adhesion, and lattice bar (D13x 250mm mesh) was set upon the surface of old concrete and below the surface of new concrete to reduce cracks (see Figures 7b, c).

4.4.3 Concrete production and placing

Concrete was produced in the on-site plant, and carried to the dam crest by dump trucks (4ton). Then, concrete was cast to a rectangular bucket ($2m^3$, see Figure 7d), and transported to the appointed place by the crawler crane (90ton). Concrete was placed to each section with a width of 2m and a length of 5m by the layer method which could ease worker's movements by keeping the same elevation between blocks, and concrete was compacted by vibrators (see Figures 7e, f, g).

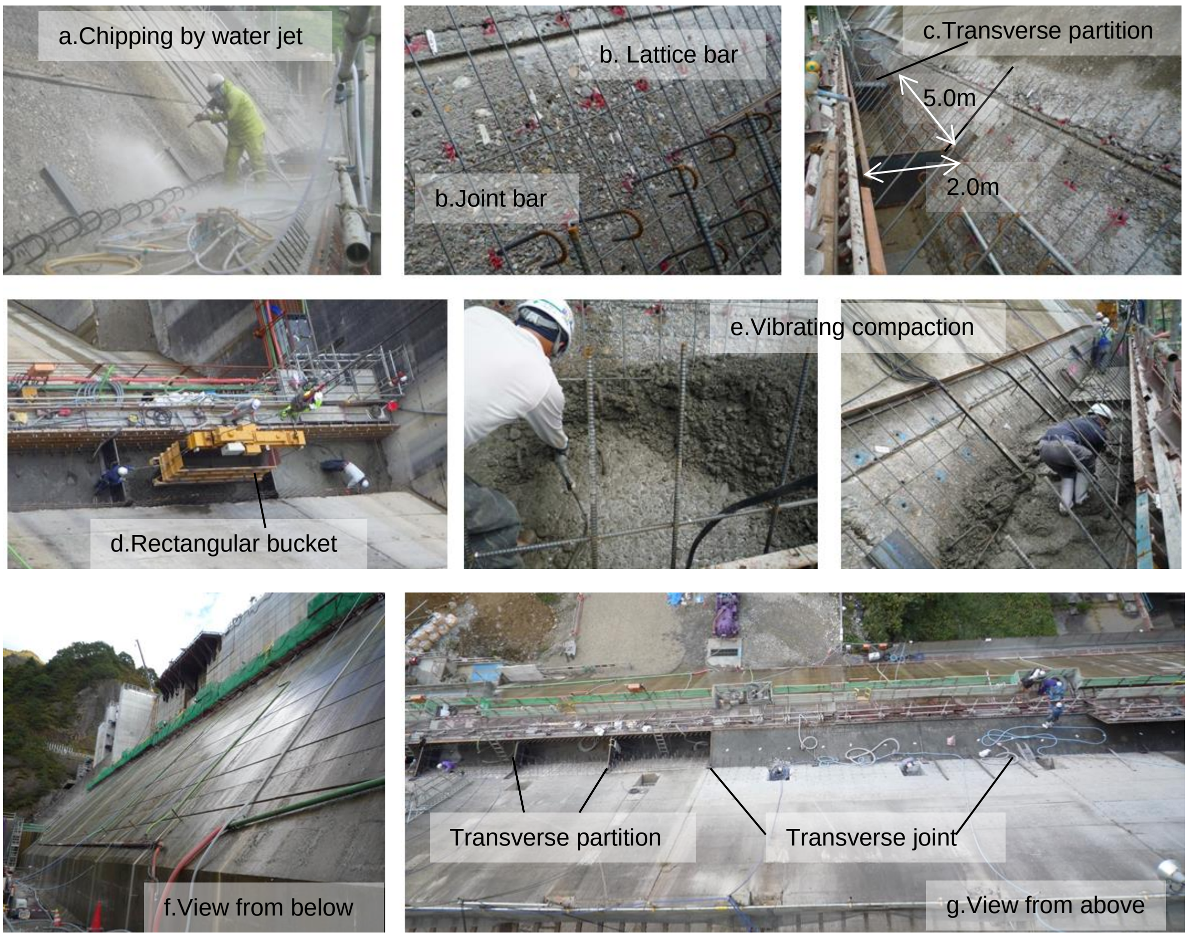

Figure 7. Situation of concrete placing on the downstream surface

4.4.4 Curing by heat supply

Since this dam site is in a heavy snowy area, work pauses in the winter. In this time, cracking is easy to occur with increasing of internal and external constraints. In order to suppress these cracks, overwinter lifts were covered by three layers of closed cell sheets, highly adiabatic mats, and blue sheets to secure 0°C or more on the concrete surface by heat supply. In addition, by creating a space by providing a roof on the overwinter lift, the effect of heat curing was enhanced.

4.5 Monitoring

In order to confirm structural stability and cracking during the heightening, it is quite important to monitor the dam body by measuring external and internal behaviours. The following measurements have been made at the Kasabori dam.

- External displacement of the dam: It has been measured since the autumn of 2016 by a light wave survey using prisms and a total station in two dam directions (the dam axis direction and the upstream-downstream direction), and no displacement which could lead to unusual dam behaviour has occurred until this time (January 2017).
- Internal displacement of the dam: It was measured since February, 2016 by a temporary plumb line in the old elevator shaft in the dam center section. No displacement which could lead to unusual dam behaviour has occurred.
- Internal strain: In two cross sections, BL-2 and BL-8, buried meters, such as a strain meter, a joint meter, a shear extensometer, and a stress meter, were installed in the foot part of the new concrete, the wintering lift, the old dam crest, etc..

5. SPEED UP AND FACILITATION OF COMPLICATED WORK SITE BY PRECAST USE

The Kasabori dam heightening increased the necessary height of the crest gates. Thus it was also necessary not only to renew the entire gate but to also rebuild structures around the overflow section such as gatepost, curtain walls, hoist machine base, etc. In addition, due to the time limit on the project, the actual period when the gate renewal and surrounding reconstruction could be executed was limited to the non-flood period in 2 years excluding the winter seasons. Therefore, it was quite important to shorten the construction period and facilitate the complex processes.

In the Kasabori dam, many precast forms were used more than ever in dam construction. Construction order and configuration by the precast use surrounding the No.1 gate is shown in Figure 8. The precast forms are used are on gateposts, a curtain wall, the upstream side of the crest, a machine base, etc. The process of the precast use was repeated simply like as “setting of supports, setting of precast forms, setting of steel bars, placing of concrete”. As a result of the precast use, it contributed greatly to shorten the construction period by utmost total 170 days, and improved the worker’s safety by reducing high place works. The following is individual merits of the precast use.

- Gatepost side of No.1 gate (see Figure 9a): Due to no need of outside scaffolds, a gate assembling was proceeded smoothly (approximately 10 days shortening).
- Curtain wall of No.1 gate (see Figures 9b,c,e): Due to no need of conventional forms and supports, a gate setting was enabled right after concrete placing (120 days shortening). Due to no need of removal of forms and supports, gate work started earlier (30 days shortening).
- Gatepost side of No. 2 gate: Due to no need of outside scaffolds, a gate assembling was proceeded smoothly without time loss (10 days shortening). Although the structures surrounding No. 2 gate were also done by the same process as No.1 gate, there was no curtain wall and it was changed by the crest girder bridge.
- Overhang section of a spare gate: Due to no need of supports, it became possible to operate an existing spare gate until just before updating (reduction of inoperable period from maximum 1.5 years to one month).
- Upstream surface of dam crest (see Figures 9d): The existing intake water tower interfered assembling conventional forms, but its work was made possible by using precast forms.

Although the current precast costs more than conventional form because of the high cost of molds, in future, with spreading of use, it can be counted on to greatly contribute to shortening construction periods and facilitating work at complex construction sites.

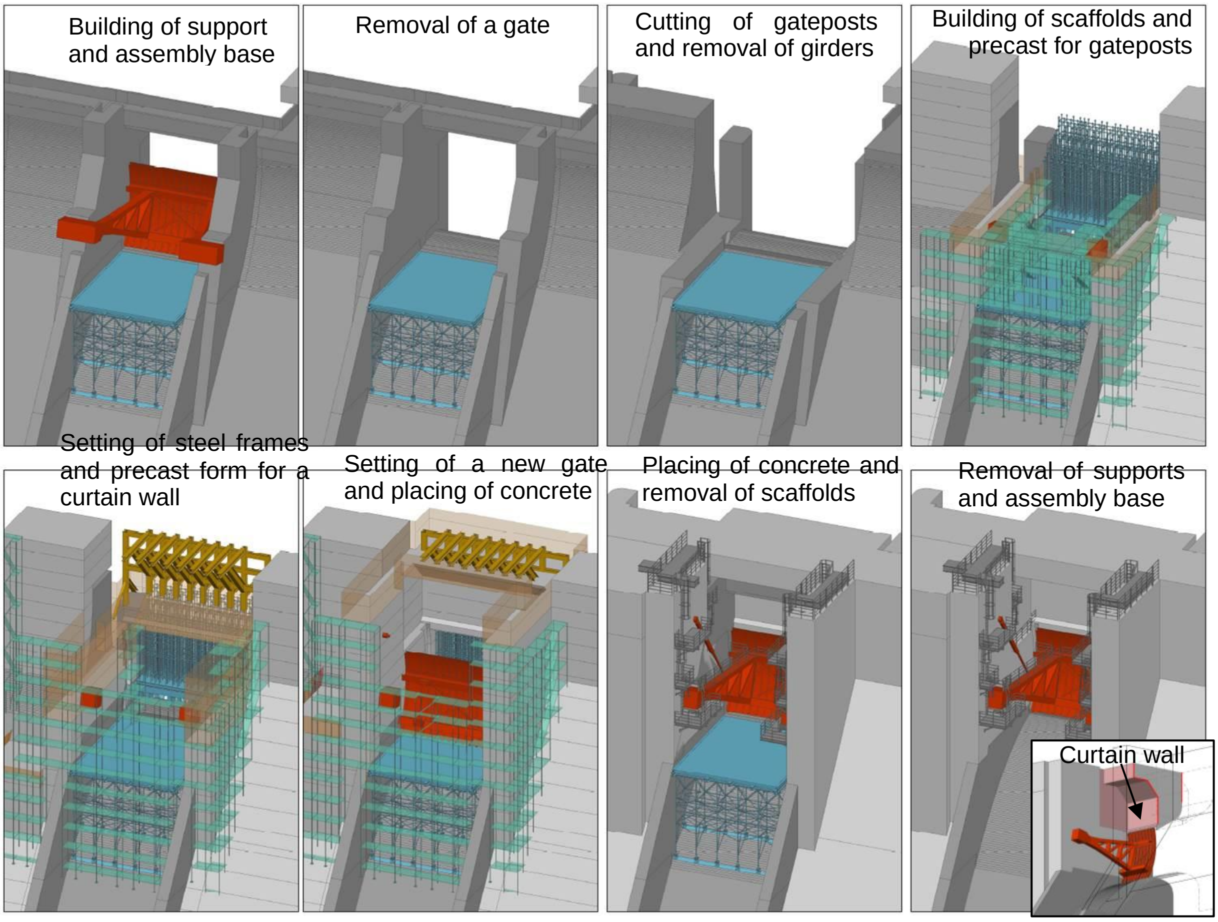

Figure 8. Construction order by using precast form surrounding No.1 Gate

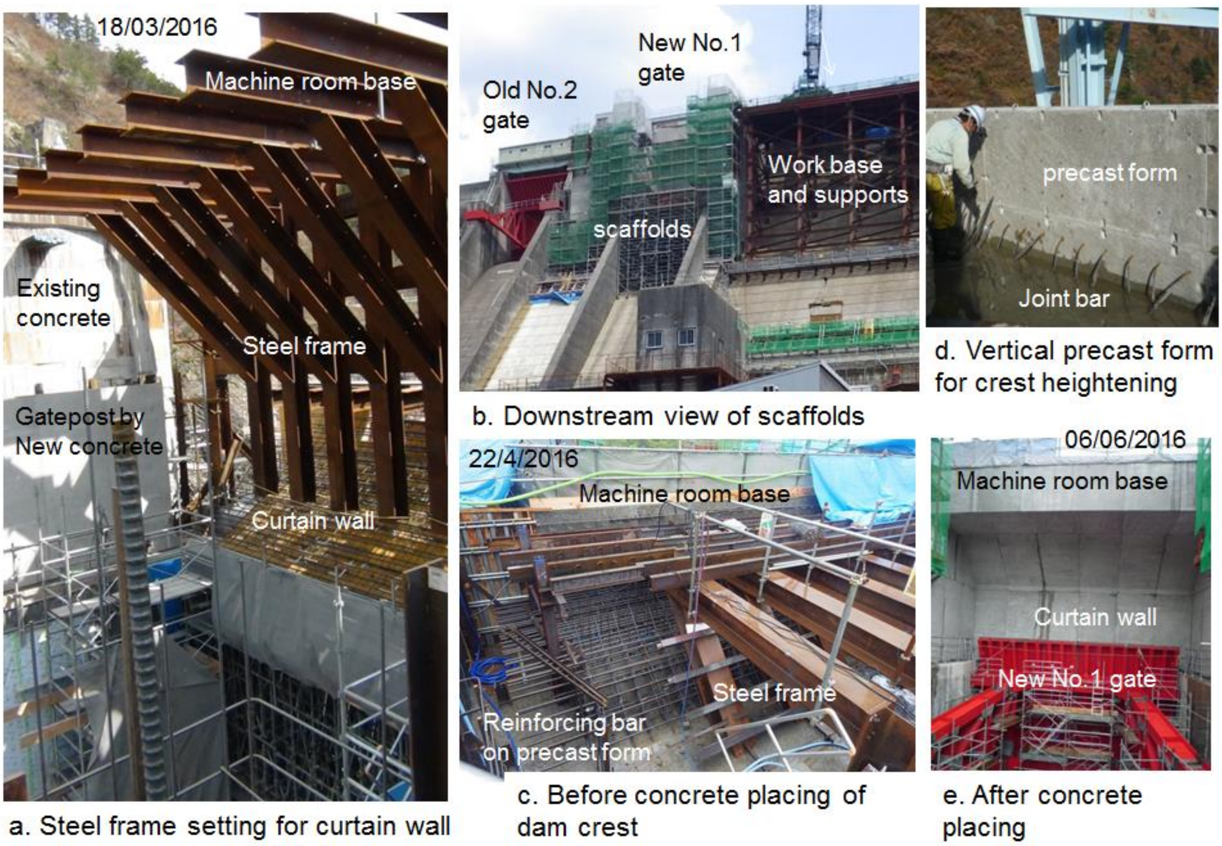

Figure 9. Construction situation using precast form surrounding No.1 Gate

6. CONCLUSION

6.1 Rational design of dam heightening and safety evaluation

- Basic dam design: The reservoir plan to enhance the flood control function was decided by heightening the dam by 4m. The unique shape adding the rising part from the middle of the downstream side was designed by comparing the downstream gradient and the foot elevation of the new concrete, and also by considering the necessary width of dam crest.
- Spillway and gates: The improvement of water ways consists of heightening walls, building a separate wall, and replacing slabs, designed by the hydraulic model experiment according to the dam heightening. Also, by this experiment, the renewal of crest gates was decided, and the reconstruction of their surrounding structures was designed.
- Seismic safety evaluation: Dynamic FEM analysis was implemented in the level 2 earthquake motions. The result showed that although tension cracking occurred in the upstream toe, the cracks did not become continuous. Moreover, around the foot of the new concrete, stress was lower than the tensile and compression strength.

6.2 Solutions for less-cracking and unification of new and old concrete

- Temperature stress analysis: Although cracking risk to the longitudinal direction was reduced by the basic measures against temperature cracks, cracking risk to the transverse direction remained according to the change of lift schedule.
- Block splitting: Dividing of block length to 5m was confirmed as the most effective measure against cracking by the three dimensional analysis. This new way was executed by transverse partitions which greatly reduced tensile stresses in the dam axis direction.
- Chipping and unification of new and old concrete: Chipping was carefully performed by water jets, and sufficient reinforcing bars were s installed.
- Mixture proportion: This area freezes in winter, so indoor freeze-thaw tests of concrete specimens were performed, and then aggregates and concrete mixture proportions for which frost-resistance was verified were selected.
- Concrete work: Concrete placing on the downstream surface has been done since May 2015 in tight schedule, avoiding summer and winter season when it is hot and cold. Now in January 2017, the monitoring data from the buried meters have shown no sign of cracking.

6.3 Speed up and facilitation of complicated work site by precast use

- Condition of the project: It was restricted in short term by the financial and natural condition. Furthermore, the project was requested to continue the dam operation, and it included many complicated construction sections.
- Precast use: Many kind of precast forms were used more than ever, and they greatly shortened the construction period by utmost 170 days, because of great reduction of setting and removing of scaffolds, or concrete forms. At the same time, the precast use facilitated complex works by simplifying on-site process, and increased the safety of high place works.
- Cost: Economic efficiency will be improved by increasing of the number of precast use.

In conclusion, we would be delighted if our experiences outlined above contribute to the future advance of dam heightening technology.

7. ACKNOWLEDGEMENTS

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