Thermal Stress Analysis of RCC Dam in Tropical Region

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1. Objective

When drawing up a temperature regulation plan for a concrete dam, it is necessary to perform temperature stress analysis according to lift schedule to identify the relationship between intensity and restricted stress generated by the dam concrete. There are 2 cases, the external restraint by the bed rock etc and the internal restraint by uneven temperature change of the concrete. Therefore, it is necessary to consider the compounded state when temperature stress analysis is done. In the case of temperature regulation plan, it is common to carry out temperature stress analysis using the FEM. In Japan where there is a high fluctuation in ambient temperature, restriction of the concrete placing temperature to about 25 deg. C or lower is adopted in summer. The Kinta Dam started construction work in January 2003, is the first RCC dam in Malaysia (dam height = 85m; length = 760m; RCC volume = 900,000m^3). The climatic condition in Japan and that of the tropics differs greatly. In view of the very few examples of temperature stress analysis studies carried out in the tropics, Hazama has taken this opportunity to carry out a thorough analysis for the purpose of preparing a temperature regulation plan for the construction of the Kinta Dam.

2. Thermal stress analysis

2.1 2-Dimensional Finite Element analysis

(1) Analysis model and condition

A 2-dimensional FEM analysis approach, as is usually carried out in Japan, was performed. A commercial software referred to as ASTEA-MAX was used for the analysis. Mixed proportions of RCC is as shown in Table-1. The thermodynamic physical properties were adopted from JSCE Standards and the values are as shown in Table-2. Placing temperature is 32 deg.C. Each lift thickness is 30cm.

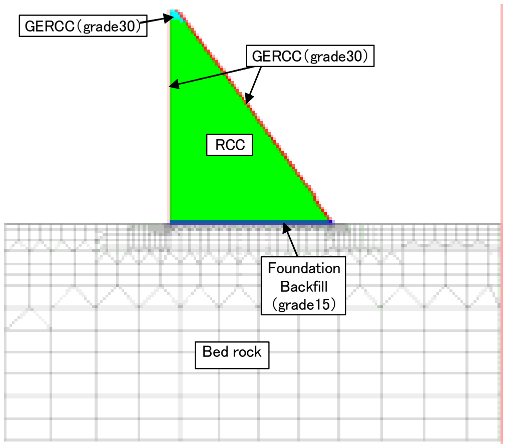

Figure-1 Analysis model (2D)

(2) Result of the analysis

The probability of temperature crack occurrence is determined by crack index, obtained by dividing the tensile stress. The target crack index is greater than 1.2. The maximum temperature distribution and the minimum value of temperature crack index is shown in Figure-2. The temperature division is due to idling period of RCC lift schedule. In the 2-dimensional analysis, due to external restraint, the crack index at the bed rock area is lower than 1.2. Therefore, it is necessary to reduce the placing temperature at this area to less than 32 deg. C.

Table-1 Mix proportion for RCC

	Gmax (mm)	VeBe (sec)	Water cement ratio W/C (%)	air air (%)	Percent fine s/a (%)	AE Reducer A1 (%)	Unit weight (kg／m3)								
							Water W	Cement (OPC) C	Slag S	Fly ash F	Fine aggregate S	Coarse aggregate 63～40mm G1	Coarse aggregate 40～20mm G2	Coarse aggregate 20～5mm G3	AE Reducer A1
RCC	63	12-17	61	1.5	45	0.25	110	55	35	90	936	232	463	463	0.450

Key-Words RCC, Thermal stress analysis, Tropical region, Placing temperature
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2.2 3 Dimension Finite Element analysis

(1) Analysis model and condition

The RCC method of construction currently adopted in other countries except Japan, the transverse joint interval is longer than 15m in many cases. In Kinta Dam, transverse joint is at 30m interval. The 3-dimensional analyses were carried out in the direction of the dam axis to check for safety. An analysis model is shown in Figure-3. By changing the design conditions, thermal expansion is considered as 6×10^{-6}/degree C. The placing temperature was at 30 degree C. For the 3-dimensional analysis, the element division method and the lift schedule were simplified for the purpose of shortening the calculation time.

(2) Result of the analysis

The maximum temperature, principal stress and the minimum value of crack index are shown in Figure-4. The results differed slightly from those of 2-dimensional analysis. The crack index is higher than 1.2 with placing temperature of 30 deg. C.

Table-2 Thermal-physical property

Characteristic Value	Value (RCC)
heat conductivity	2.7W/m℃
specific heat	1.15kJ/kg℃
density	2386Kg/m^3
Film coefficient	14W/m^2℃
Adiabatic temperature	$Q(t) = Q_\infty(1-\exp(-0.09t))$ $Q_\infty=20.0$℃
thermal expansion	10×10^{-6}/℃
Poisons ratio	0.2
Compressive strength	$f'c(t) = t/(6.2 + 0.93t)\times20$ MPa
Modulus elasticity	$Ee = \Phi(t)\times4700\sqrt{(f'c(t))}$ MPa
Tensile strength	$f\,t(t)=0.35\sqrt{(f'c(t))}$MPa

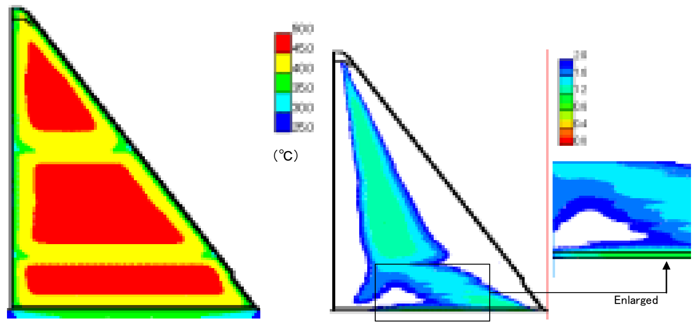

Figure-2 Distribution of maximum temperature and minimum crack index

3. Consideration / Conclusion

From the analysis results, with placing temperature at 30 deg. C for dams in the tropical area, there are minor temperature stress problems and can be disregarded. This is due to the same annual ambient temperature and the same placing temperature. However, it is necessary to consider the bed rock area due to external restraint. The difference between the 2-dimensional and 3-dimensional analysis is due to the difference of models such as lift thickness and size of an element; differed condition such as thermal expansion coefficient. The physical properties of cement and flyash used in the analysis are based on assumed values. It is necessary to carry out further tests on actual materials to be used.

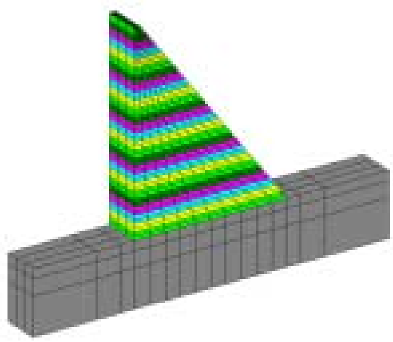

Figure-3 Analysis model (3D)

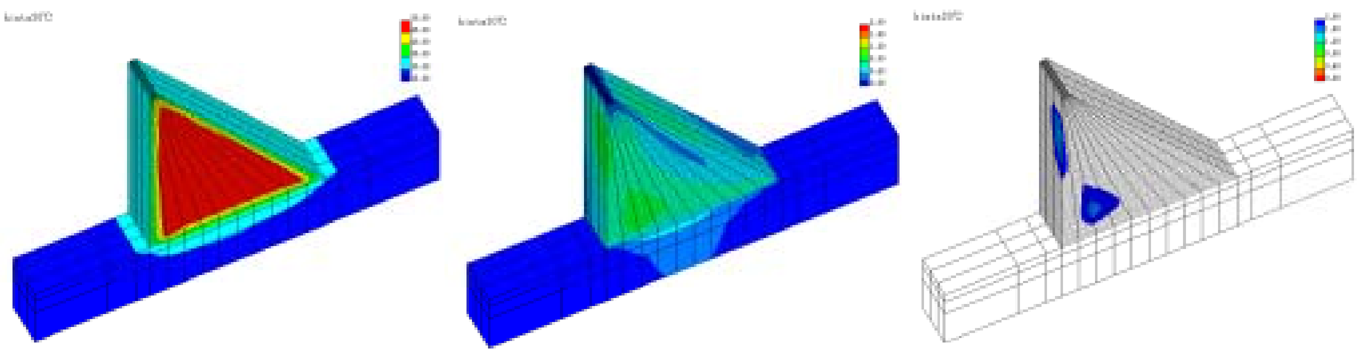

Fig-4 Distribution of maximum temperature, stress and minimum crack index (From the left side)