Thermal Stress Analysis of RCC Dam in Tropical Region

HAZAMA Malaysia Office Toshiyuki TEMMYO, Toshiya HOSONO
Sg. Kinta SKH Consortium GO CHEE SIANG, Ponnosamy
HAZAMA Civil Engineering Division Ritsu SUGIYAMA

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 = 900,000m³). 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.
(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

<table>
<thead>
<tr>
<th></th>
<th>Gmm</th>
<th>Vebe</th>
<th>Water cement ratio WC (%)</th>
<th>air (%)</th>
<th>Percent fine s/a (%)</th>
<th>AE Reducer (%)</th>
<th>Water</th>
<th>Cement (OPC)</th>
<th>Slag</th>
<th>Fly ash</th>
<th>Fine aggregate</th>
<th>Coarse aggregate</th>
<th>AE Reducer</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCC</td>
<td>63</td>
<td>12-17</td>
<td>61</td>
<td>1.5</td>
<td>45</td>
<td>0.25</td>
<td>110</td>
<td>55</td>
<td>35</td>
<td>90</td>
<td>936</td>
<td>232</td>
<td>463</td>
</tr>
</tbody>
</table>

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No.1-6 6th, The Boulevard, Mid Valley City, Lingkaran Syed Putra, 59200 Kuala Lumpur  TEL:+603-2282
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 6x10^-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.

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.