Thermal Analysis of SHAHRIKOR RCC DAM

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Abstract

Concrete dams thermal Analysis is required both in design and construction stage for checking the cracking of dam body due to trapped heat. Calculation of this heat is a complicated process due to layer by layer construction method. Cracking due to thermal change in dam body could cause leakage or instability and will increase costs of the project. In this paper, SHAHRIKOR dam thermal analysis is presented which has been performed to ensure there will be no crack in the dam body due to the heat generation of cement. Hydration of Cement is an exothermic chemical reaction and heat will increase the reaction rate. So, for a more precise analysis, effect of heat on hydration rate should be considered in calculations. A finite element model has been prepared by using ANSYS finite element software, with consideration of dam body time schedule, lift thicknesses and non-linear effect of heat on hydration rate. In this paper Mass gradient cracking risk has been calculated also which shows that no cracking risk exist. Effect of two placing Temperature 26℃ and 32℃ have been investigated on peak temperature in dam body. Calculations showed that by decreasing the placing temperature from 32℃ to 26℃, peak temperature in the dam body will be decreased only 1.13℃. This result showed that 32℃ placing temperature is more economical than 26℃.

Keywords: Thermal Analysis, RCC dam, heat generation, Finite element, SHAHRIKOR dam.

1. INTRODUCTION

Thermal analysis is conductedin concrete dams to ensure the reliability of the dam body's stability and serviceability during changing its internaltemperature. Concrete dams' thermal analysis is divided into two categories:

First type is the study of the service thermal analysis whichis the analysis of thermal loads due to the water,ambient and other loads that will be applied to the dam body.These loads can affect the stability of the dam body and inner stress conditions.The Second type is the construction thermal analysis, which tensile stresses and subsequent cracking (in different elevations in dam body) due to the cement heat of hydration, convection and other related items coming from construction method or ambient condition is calculated. In concrete dams, thermal analysis is performed for below reasons:

- Definition of a safe maximum placing temperature for fresh concrete
- Definition of precooling and post cooling system capacity
- Definition of concrete blocks length
- Definition of the optimum lift thickness
- Definition of safe time interval between successive lifts with consideration of probable stops during concrete placing
- Definition of the best time for start of the dam body
- Definition of the best arrangement of instrumentation

2. HEAT DISTRIBUTION IN MASS CONCRETES

Mass concrete is any volume of concrete with dimensions large enough to require that measures be taken to cope with the generation of heat from hydration of the cement and attendant volume change to minimize cracking [1].Increasing heat in mass concrete finally will cause its contraction and cracking. Therefore,to satisfy the engineering requirements the thermal control is a mandatory. Heat distribution calculation is a complicated process because mass concrete structures are placed layer by layer. Time interval between two successive lifts will make it even more complicated. Total heat distribution equation could be expressed as below:

$$k_{xx}\frac{\partial^2 T}{\partial x^2}+k_{yy}\frac{\partial^2 T}{\partial y^2}+k_{zz}\frac{\partial^2 T}{\partial z^2}+w=\rho c\frac{\partial T}{\partial t} \quad (1)$$

WhereT is body temperature, k is thermal conductivity, ρis specific gravity, c is specific heat and w is heat generation. What is important in this equation is correct boundary conditions. Boundary conditions are points with constant temperature, convection or radiation.

3. EFFECTIVE FACTORS IN CEMENT HYDRATION

Hydration depends on different factors e.g. cement chemical composition, water cement ratio, fineness and size distribution of cement grains.Hydration is a thermoactivated reaction which means that reaction rate will be increased with increasing in temperatureand vice versa. (See Figure 1). For cement increasing the temperature will increase rate of reaction and so increase heat generation. Since generated heat depends on heat generation rate, so for a more precise analysis, heat generation rate shall be considered in the finite element model of the dam body.

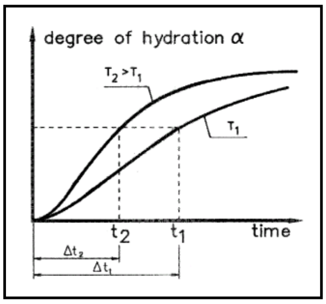

Figure 1. Time and temperature effects on hydration rate

Effect of heat on hydration rate is explained as below [2]:

$$H(T)=e^{\frac{Ea}{R}(\frac{1}{T0}-\frac{1}{T})} \quad (2)$$

T is concrete temperature at time of calculation and T0 is datum temperature of reaction (equals to 293 Kelvin) and for Portland cement R is 8.31J/mol.K. Ea is activation energy and could be expressed as below expression [2]:

$$Ea(Kj/mol)=\begin{cases}33.5 \therefore T>20°C\\ 33.5+1.47(20-T) \therefore T<20°C\end{cases} \quad (3)$$

Many expressions have been presented for mass concrete heat generation which one of them is proposed by USBR [3].

$$Q=Q_m(1-e^{-m.te}) \quad (4)$$

In above expression, Q_m and m are coefficients that depends on cement type and its heat generation. te is equal age or maturity which will increase withincreasing time and temperature.Therefore, heat generation rate relationship with time can be expressed as 6.

$$te=\int H.dt \quad (5)$$

$$Q^{\cdot}=\frac{\partial Q}{\partial te}.\frac{\partial te}{\partial t}$$

$$Q^{\cdot}=(me^{-mte}).H \quad (6)$$

4. CRACKING IN MASS CONCRETE STRUCTURES

Equation 7 is presented by ACI 207.2R that shows the resulted strain in concrete due to temperature difference where, α is the coefficient of thermal expansion of concrete and ΔT is temperature difference [4]

$$\varepsilon = \alpha \times K_R \times K_F \times \Delta T \qquad (7)$$

Also, K_R is the internal restraint degree as a result of structure and foundation geometry which differs from 1 to 100 percent and obtained from equations 8 and 9:

$$\frac{L}{H} \geq 2.5 \qquad K_R = [\frac{(\frac{L}{H}-2)}{(\frac{L}{H}+1)}]^{\frac{h}{H}} \qquad (8)$$

$$\frac{L}{H} < 2.5 \qquad K_R = [\frac{(\frac{L}{H}-1)}{(\frac{L}{H}+10)}]^{\frac{h}{H}} \qquad (9)$$

where h is height from foundation. K_F(foundation restraint) is also defined as Equation 10:

$$K_F = \frac{1}{[1+(\frac{A_g \times E_g}{A_F \times E_F})]} \qquad (10)$$

where A_g and E_g is the concrete lift area and its modulus of elasticity respectively and A_F and $E_F$are the area and modulus of deformation of the foundation.
Cracking types in mass concrete structures which is created due to thermal stresses are divided into two types:

4.1 SURFACE GRADIENT THERMAL CRACKING

This type of cracking occurs during cold months due to surface thermal gradient in concrete structure and will be visible in first few days after concreting. For prevention of this type of cracking,temperature difference between internal and external temperature of concrete shall be limited. Technical specifications generally advise to increase time of demolding in comparison with normal conditions or use suitable insulation. This type of cracking has a lower degree of importance because of lower depth and opening. After diminishing thermal gradient between internal and external part of the concrete structure, cracks are almost closed. This type of cracks has no harmful effect of watertightness or structural behavior of the dam body.

4.2 MASS GRADIENT THERMAL CRACKING

The mass gradient thermal cracking is created while concrete is placed in the warm months and cools down to final stable temperature. These cracks are generally visible at later ages after cooling of concrete(e.g. cooling concrete to closure temperature in concrete dams). Probability of occurrence of this type of cracking is higher in areas near foundation rock because of higher restraint. These cracks could be prevented by decreasing concrete peak temperature or cooling rate. These types of cracks are wide enough and will harm permeability of structure and generally penetrate into dam body.

5. PARAMETERS HAVE BEEN USED IN THERMAL ANALYSIS

There are several effective parameters that is effective on this analysis results. In this section the most important ones such as materials and assumptions are presented.

5.1 DAM BODY GEOMETRY

Shahrikor dam is an RCC dam with a height of 56m and crest length of 335m located at confluence of Barisan and Kozour rivers in Sistan va Baluchestan province in south east of Iran. It should be mentioned that highest block due to its larger dimension and higher restraint has been selected for thermal analysis. Longitudinal section of dam body is shown in Figure2.

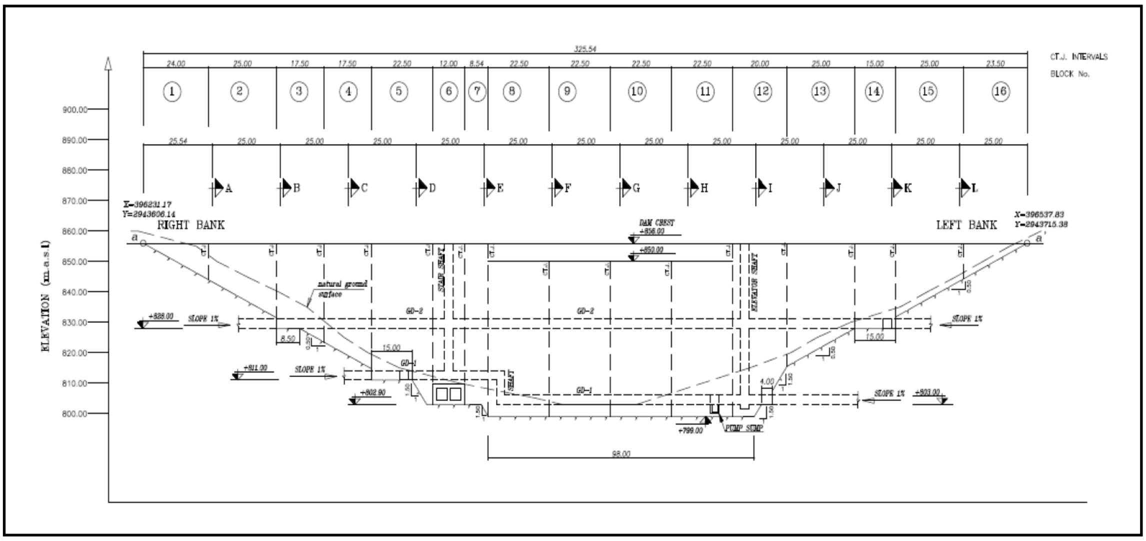

Figure 2. Shahrikordam longitudinal section

5.2 AMBIENT CONDITION

Shahrikor dam located in hot area.The sinusoidal curve of mean monthly temperatures and also fresh concrete placing temperatures (without precooling) is shown in Figure 3. Based on project studies, mean annual temperature is 23.5℃.

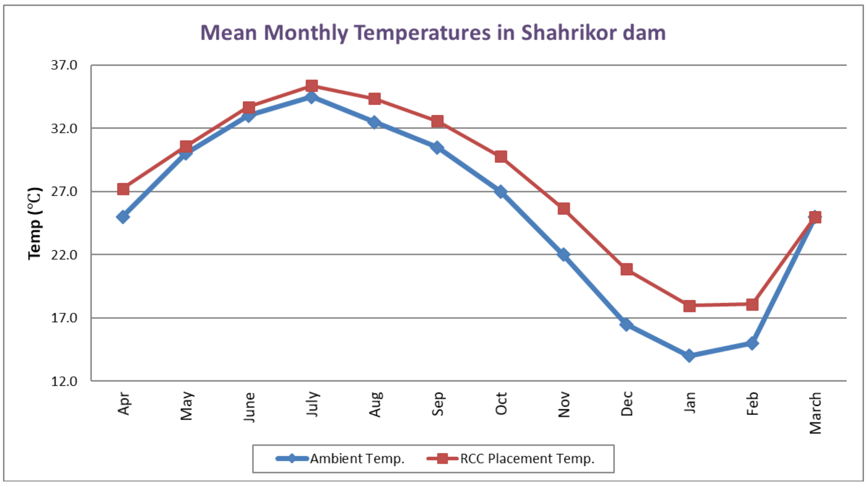

Figure 3. Monthly temperatures in the project area

5.3 MIX DESIGN AND CEMENT CONTENT

Based on Mix design test results, Cementitious content in RCC mix design of dam core is 160kg/m^3. However, to have a more conservative thermal analysis cement content is considered to be 180kg/m^3 in the analysis. Pozzolanic cement heat generation is 60cal/gr and 67cal/gr at 7 and 28 days respectively but will be considered in the analysis as 65cal/gr and 75 cal/gr at 7 and 28 days.

5.4 THERMAL AND STRUCTURAL PROPERTIES OF RCC

Other assumptions for Thermal and structural properties of Roller compacted concrete in Shahrikordam have been shown in Table1.

Table 1- Properties of RCC in the analyses

Property	RCC
Diffusivity (m^2.day)	0.113
Specific heat(J/kg.°C)	950
Density (kg/m^3)	2450
Surface TransmissionCoefficient (Kcal/m^2.h.°C)	11.6
Thermal expansion coefficient (1°C)	10×10^{-6}
Elasticity Modulus (GPa)	18
Rapid rate tensile strain capacity	-
Slow rate tensile strain capacity	80 µ
Poisson's ratio	0.2

5.5 FINITE ELEMENT MODEL

Finite element model has been constructed using Ansys 5.4. Figure 4 shows this model for thermal analysis of Shahrikordam.

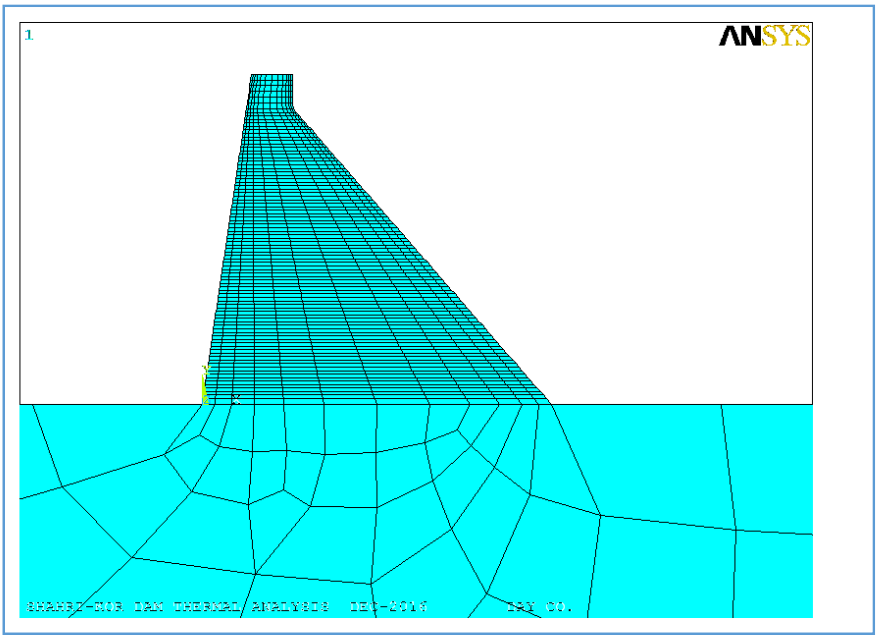

Figure 4.Finite element model for thermal analysis of Shahrikordam

5.6 CONCRETEPLACINGTEMPERATURE

Two different analyses have been performed with Fresh concrete of 26°C and 32°C. RCC temperature is dependent to the season. In the analyses whenever fresh concrete temperature exceeds 26°C or 32°C, RCC is precooled to the mentioned temperatures. Fresh RCC temperature without precooling has been shown in Figure 3.

5.7 CONSTRUCTION TIME SCHEDULE

RCC layer thickness and time lapse between two successive layers is an effective parameter in amount of heat trapped in the dam body. RCC layers thickness is 30cm and RCC placement rate has been considered one layer each 2.5 days. Based on project time schedule, start of the project is in March.

6. ASSUMPTIONS IN SHAHRIKOR THERMAL ANALYSIS

In Shahrikordam thermal analysis, below assumptions have been considered:

1. Concrete is considered isotropic and homogeneous. On the other hand, conductivity, diffusivity and other properties are considered equal in all directions.

2. Thermal and structural properties of concrete are consideredto be constantrelated to temperature variations. Also, thermal properties of concrete are considered constant at all periods of time and during progress of hydration.
3. Effect of heat of hydration rate (Maturity) have been considered in calculations. This means that by increasing the temperature hydration rate will be increased.
4. Due to the lack of precise and tested parameters, exhaust of the temperature perpendicular to plane has been neglected and a 2D model is used. Therefore,the model shows the highest probable temperature in the middle part of layers.
5. Effect of temperature fluctuations during the day have been neglected and analysis is performed with maximum monthly temperature. So, it is predicted that actual peak temperature be less than this analyses results.
6. Based on strain method, the compressive strains in the dam body is neglected conservatively
7. Water spraying on concrete surface for curing will decrease temperature of hardened concrete (surface post cooling) and increase surface transmission coefficient. This effect has been neglected conservatively.
8. Due to the high ambient temperatures of the site, surface gradient risk is very low so will not be calculated in this analysis.

7. CRACKING ANALYSES

As previously mentioned, in hot areas risk of thermal surface gradient is very low,especially in concretes with low cement content. Therefore, only mass gradient thermal analysis has been performed.

In mass gradient cracking analysis, temperature changesat different points of dam body have been calculated up to 3500 days. Figure 5&6shows isothermal curves on 300 days and 800 days after start of construction. Figure 7 shows temperature change history in dam body up to 3500 days after start of dam body construction. Foundation deformation modulus is 11.57GPa. Opening of contraction joints has been considered 1mm.

In the calculations, restraint factor (K_R) has been considered equal to 100% conservatively. Maximum Contraction Joints spacing is 25m and calculated crack spacing is 28m. This means that there is no risk of mass gradient cracking in the dam body.

Also based on the curves presented in Figure 7, effect of reduction of temperature from 32°C to 26°C, is negligible. This shows that based on the project construction methodology, it is possible to have higher placing temperatures with a cost reduction.

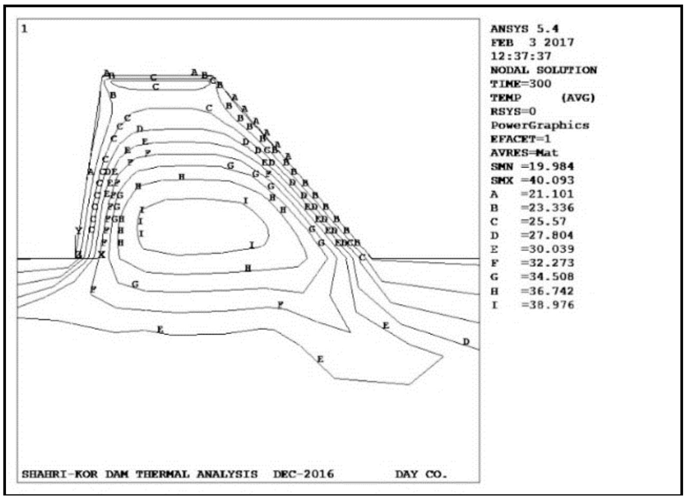

Figure 5.Isothermal curves in dam body after 300 days of start of construction (Placing temp=26°C)

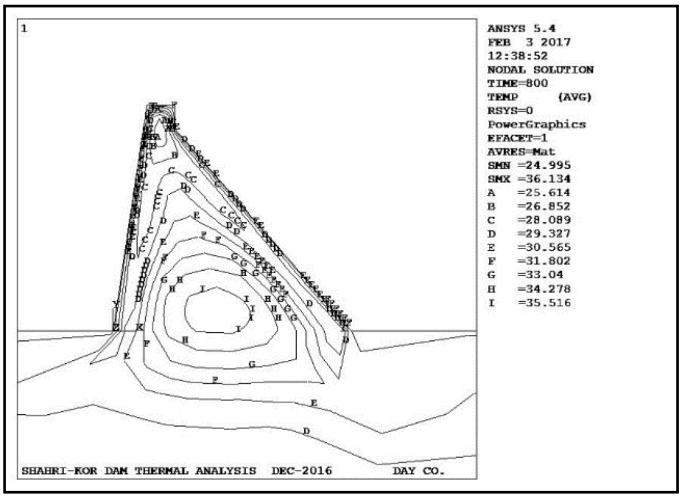

Figure 6.Isothermal curves in dam body after 800 days of start of construction (Placing temp=26℃)

According to temperature history in the dam body, maximum temperature in dam body will be generated with 32℃ placing temperature. Calculations shows that with 42.25℃ peak temperature,Crack spacing will be 28m.So, because of conservative assumptions and maximum 25m contraction joint spacing, nocrack will exist in dam body.

Table 2- Peak Temperatures in different elevations at center of the dam

NODE	X	ELEV.	PEAK(MAXPL26)	PEAK(MAXPL32)
116	29.288	801.2	40.16	41.06
458	27.33	806.6	41.13	42.25
800	25.373	812	40.47	41.6
1236	23.089	818.3	35.27	35.78
1598	20.805	824.6	31.19	31.41
2016	18.412	831.2	30.75	30.85
2472	15.802	838.4	32.79	32.89
2890	13.41	845	37.46	38.37

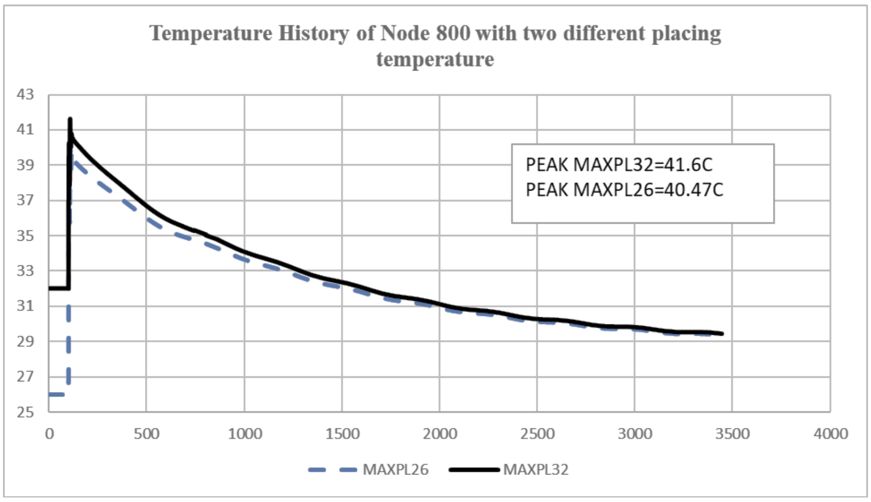

Figure7-Temperature History in Node 800 with two different placing temperatures

8. CONCLUSION

In this paper, thermal analysis of Shahrikor dam has been presented. Effect of two different Maximum placing temperature have been analyzed on Peak temperature in dam body. In this regard the following conclusions can be drawn [5]:

In calculation of restraint factor caused by foundation, the maximum deformation modulus has been used. This means that with 32℃ placing temperature no cracking will exist in the dam body.

1. In calculation of mass gradient cracking risk, restraint reduction in higher elevations has not been encountered (K_R=1). It is evident that in higher elevations restraint factor is reduced and so thermal tensile strains is reduced.
2. Water Spraying on concrete surface will help in reduction of concrete temperature and prevention of heat absorption from sun light.
3. Placing concrete at night and using shades on aggregates deposits is a mandatory specially in warm months. Amount of retarder shall be increased in warm month.
4. In this paper effect of increasing Maximum placing temperature on mass gradient cracking risk has been investigated. Calculations shows that there is only a 1.13℃ difference in peak temperature between two cases. It is evident that with this negligible difference between these two maximum placing temperatures, using 32℃ is more economical. So, a Maximum pacing temperature of 32℃ is used in the project.

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