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Evaluation on Heat of Hydration in Roller Compacted Concrete Dams during Construction Phases

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Abstract: In this research work a finite element formulation for temperature distribution in roller compacted concrete dams exposed to time – variable parameters has been worked out and then the most effective application of the developed software is the analysis of a roller compacted concrete. Which is in the feasibility phase of study by the consulting engineer. The parameters such as clarification property of concrete, atmospheric temperature, delay in concrete placing and the temperature distribution in the rock ground before start of the casting of the concrete? The behavior of the roller compacted concrete dam section has been studied by dividing it into 15 stages of construction .It was seen from the plots of temperature distribution at different elevation of the dam , except for the initial lift (lift No.1) in general there is a drop in temperature at both upstream and downstream of dam and rise in the inner portion of the dam. Also due to presence of gallery there is drop of temperature in the surrounding zone.

Key words: Reservoirs**,** Hydration, Roller Compacted Concrete Dam

INTRODUCTION

Design considerations the largest volumetric change in roller compacted concrete dam's results from the change in temperature. The rate of change in temperature is a consequence of cement hydration which is an exothermic reaction that introduces temperature gradients in the roller compacted concrete dam body.

In the stress analysis of a roller compacted concrete dam, the evaluation of stress is considered to be more complex than normal gravity dam. This is due to fact that in the roller compacted concrete dam there is a tendency to construct the dam without joints .Therefore in such case, thermal loading is of major concern since the dam must carry the induced stress caused by a constantly changing temperature during the construction phase and the following cooling period.

The two – dimensional analysis of concrete gravity dams during its construction phase was analyzed by Araujo *et al*. (1998) by using the finite element method. Also, Saetta *et al*. (1995) presented the stress- strain analysis of concrete structures exposed to time and space variable thermal loads by using the finite element technique.

Also, for the thermal analysis of mass concrete with finite element method, (Ishikawa (1991)) suggests the consideration of the following two conditions:

- The value of the elastic modulus of concrete should increase with time.
- Finite elements should be added according the casting schedule of concrete.

Finite Element Formulation for Solving Time Dependent Temperature:

The bidimensional heat transfer problem is governed by the differential equation (Fourier's law):

$$\frac{\partial}{\partial x}(k_x\frac{\partial T}{\partial x})+\frac{\partial}{\partial y}(k_x\frac{\partial T}{\partial y})+Q=\rho c\frac{\partial T}{\partial t} \qquad (1)$$

The temperature values at the nodes of the finite element mesh are assumed to be basic variables and, therefore the temperature field can be expressed as:

$$T=[N]\{T\} \qquad (2)$$

The general procedure for analyzing Equation (1). is to evaluate the Galerkin residual integral with respect to the space coordinates for a fixed instant of time. The Galerkin residual integral is in the form of:

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$$\{R\}^e = \int_\Omega [N]^T (k_x \frac{\partial^2 T}{\partial x^2} + k_y \frac{\partial^2 T}{\partial y^2}) d\Omega - \int_\Omega \rho c [N]^T \frac{\partial T}{\partial t} d\Omega + \int_\Omega [N]^T Q d\Omega = 0 \quad (3)$$

Where all integrals are applied over the element domain. Integrating by parts the first term of Equation (3) using Fourier's law for heat transfer by conduction and considering
Eq. (2), the following system of linear differential equations are obtained:

$$[c^e]\{\frac{\partial T}{\partial t}\} + [k_t^e]\{T\} - \{F_t^e\} = 0 \quad (4)$$

Where $[c^e]$ is usually called the capacitance matrix which is expressed as:

$$[c^e] = \int_\Omega \rho c [N]^T [N] d\Omega \quad (4\text{-}1)$$

And

$$[k_t^e] = [k_k^e] + [k_m^e] \quad (4\text{-}2)$$

Where $[k_k^e]$ is stiffness matrix for field problems and $[k_m^e]$ is boundary stiffness matrix for field problems?

$$[k_k^e] = \int_\Omega [B]^T [D][B] d\Omega \quad (4\text{-}3)$$

Where: $[D] = \begin{bmatrix} kx & 0 \\ 0 & ky \end{bmatrix}$

$$[B] = \begin{bmatrix} \frac{\partial [N]^T}{\partial x} & \frac{\partial [N]^T}{\partial y} \end{bmatrix}$$

$$[k_m^e] = \int_u h [N]^T [N] du \quad (4\text{-}4)$$

And

$$\{F_t^e\} = \{F^e\} + \{F_s^e\} \quad (4\text{-}5)$$

$\{F^e\}$ Is the element force vector, $\{F_s^e\}$ is the element force vector in boundary condition:

$$\{F^e\} = \int_\Omega Q [N]^T d\Omega \quad (4\text{-}6)$$

$$\{F_s^e\} = \int_u T_{env} h [N]^T du \quad (4\text{-}7)$$

These equations must be solved before the variation of T in space and time is known. There are several procedures for numerically solving the Equation (4).We used a finite difference approximation in the time domain to generate a numerical solution (Segerlind (1984)):

$$([c] + \theta \Delta t [k_t])\{T\}_b = ([c] - (1-\theta)\Delta t \ [k])\{T\}_a + \Delta t((1-\theta)\{F_t\}_a + \theta \{F_t\}_b) \quad (5)$$

Where $\{T\}_b$ and $\{F_t\}_b$ are {T} and {F_t} at time b and $\{T\}_a$, $\{F_t\}_a$ are {T} and {F_t} at time a.
$0 \leq \theta \leq 1$, θ is a scaler

Araujo (1998) indicates that it is convenient to take $\theta \cong 1$ in order to avoid spurious oscillations. Then it takes following form:

$$([c] + \Delta t[k_t])\{T\}_b = [c]\{T\}_a + \Delta t\{F_t\}_b \tag{6}$$

Finite Element Simulation of Heat of Hydration in R.C.C Dam during Construction Phase:

The computational strategies with respect to heat of hydration developed in the body of the dam are summarized in the following steps.

Step.1 Take first stage of construction, divide the construction time into several time increment (in terms of hours).

Step.2 Solve Equation (6) and evaluate the temperature vector at the all nodal points.

Step.3 Accumulate the temperatures at end of every time increment:

$$\{T\}^{i} = \{T\}^{i-1} + \{dT\}^{i} \tag{7}$$

Step.4 Store the temperature vector of increment, $\{T\}^i$ as initial temperature vector for next time increment that is I + 1.

Step.5 the step 1 to 4 is repeated until the construction of the first stage is completed.

Step.6 Take next stage of construction in addition to the previous stage (Ishikawa (1991)).

Step.7 Choose time increment and then repeat the step 2 to 7 until final stage of construction is reached.

Analyzed Zirdan Roller Compacted Concrete Dam:

- ***Problem Definition:***

This dam is supposed to be constructed in the province of Baluchistan, south- east part of Iran Pirsehrab River. Figure (1) shows the typical section while the material properties are presented in Table (1).

Table 1: Temperature and material properties of R.C.C, mass concrete and rock ground.

Material	Heat Conduction Coeff. Kcal/marc	Heat Convection Coeff. Kcal/m^2 hr c	Specific Heat Kcal/Kg	Elasticity Modules T/m^2	Poisson Ratio
Rock Ground	2.30	10.00	.30	.6E+6	.30
Mass Concrete	2.40	10.00	.30	2.3E+6	.30
R.C.C Concrete	2.40	10.00	.30	1.65E+6	.30

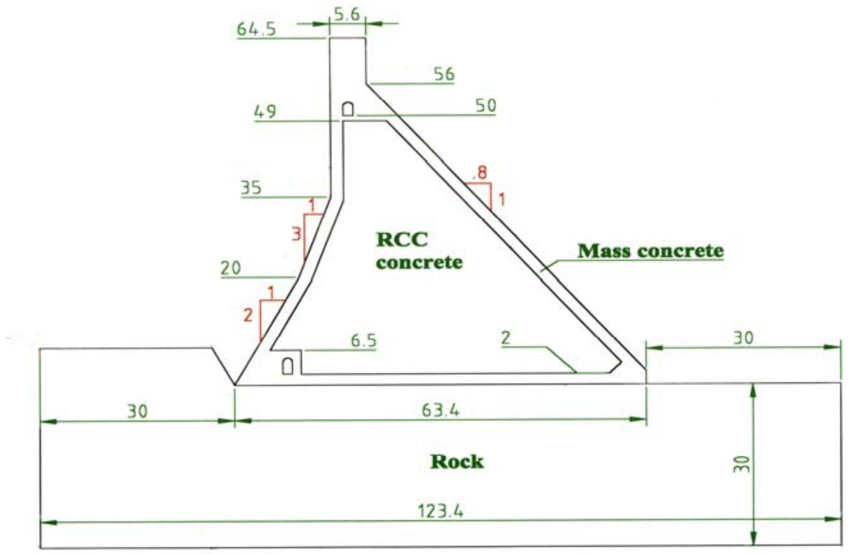

Fig. 1: Section of the Zirdan Roller Compacted Concrete Dam.

Finite elements models are prepared to the casting schedule of concrete so, here 15 lifts of construction for the finite element idealization have been assumed and accordingly 15 finite element mesh was prepared. Figure(2) shows the finite element idealization of the dam section under plane strain condition for the final stage of construction.

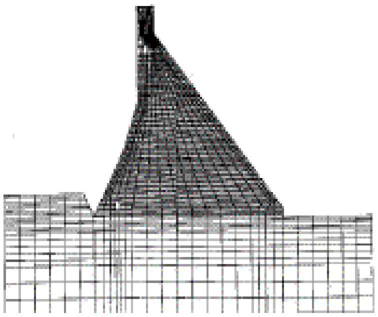

Fig. 2: Finite Element Modeling of the Dam-Foundation System.

Total number of elements=2372; Total number of nodes=2546

- ***Parameters Involved:***

a- Clarification Property of Concrete:

The clarification property of concrete (hydration) can be described as the following equation (Ishikawa (1991)):

$$\boldsymbol{T = T_{\max} (1 - Exp\ (-\beta t))} \qquad (8)$$

In the present study, in the present study $T_{\max}$ = 17 °c, and $\beta = 0.0138$ is adopted for this simulation purpose (Dungar (1988)).

b– Approximation of Atmospheric Temperature:

Generally, an atmospheric temperature is approximated with SIN function as:

$$T_{air} = T_a \sin 2\pi \left(\frac{N - D_0}{365}\right) + T_{anu} \qquad (9)$$

In this simulation: D_0 is 214.4, T_{anu} is 15.2 °C and T_a is 14.05 °C.

c – Initial Temperature of Rock Ground:

In this investigation a method to calculate, it is assumed that the initial temperature of all nodes corresponding to the rock ground is the same (27.6 °C). Changing the atmospheric temperature for two years with increment of 48 hours (total 365 increments) observed data, then the heat transfer is analyzed between the atmospheric temperature and the rock ground.

RESULTS AND DISCUSSIONS

The schedule of construction phase of the dam with respect to number of lifts, height of the dam ,thickness of each lift and age of the project at end of every lift including the delay in construction program (in days), planned by the consultant Engineers (M. Lackpour (1988)), are presented in Figure(3).

In this research work the behavior of the dam with respect to temperature variation evaluated for every stage of construction are studied .The temperature distribution at different elevation of the dam for the lift No. 4, 8 and 11 are presented in figure (4), figure (5) and figure (6) respectively.

It can be seen from these plots that in general there is a drop in temperature at both D/S and U/S faces of the dam while there is a rise of temperature in inner portion of the dam which clearly indicates the effect of atmospheric temperature. Moreover the effect of gallery in reducing the temperature is clearly seen in the above plots. After, the temperature of all the nodal points with respect to time t has been determined for a particular lift. Now, based on the work presented by (Zhu *et al*. (1999)), the value $\boldsymbol{\Delta T}$ of been calculated accordingly the stress analysis has been carried out. The variation of the principal stresses at every Gauss points are studied for every lift of construction phase. Figure (7) and Figure (8) show the plots of maximum and minimum principal stresses for temperature loading and temperature plus dead weight of the dam respectively.

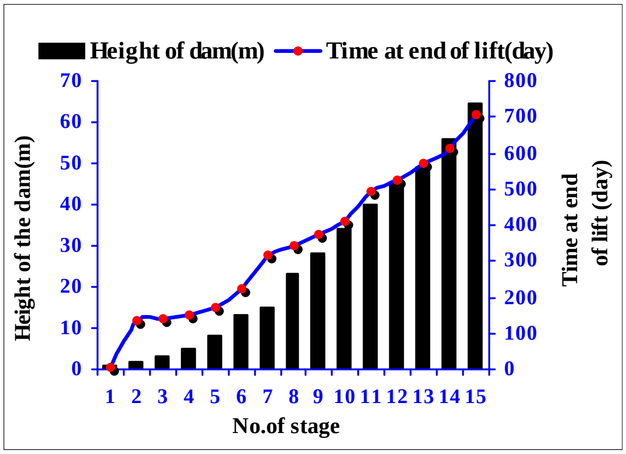

Fig. 3: Construction Phase of the dam.

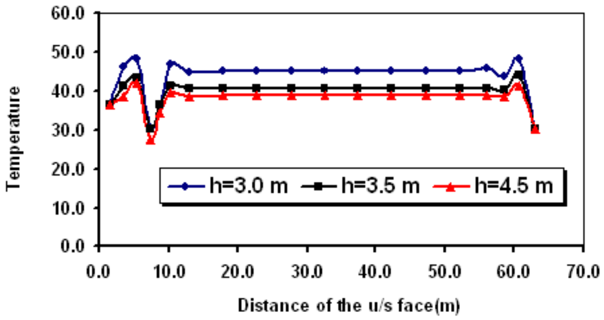

Fig. 4: Temperture distribution at lift no 4.

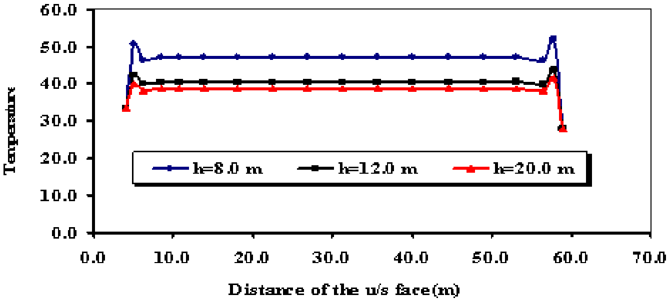

Fig. 5: Temperture distribution at lift no 8.

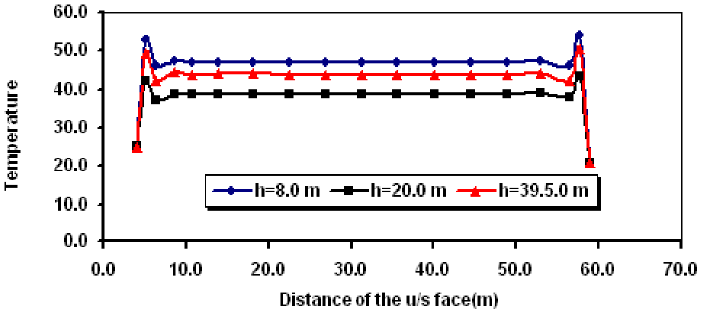

Fig. 6: Temperture distribution at lift no 11.

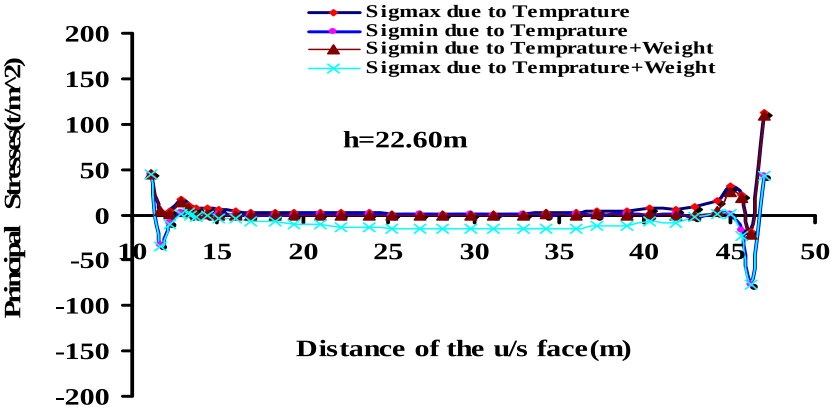

Fig. 7: Variation of principal stresses for lift N O. 8.

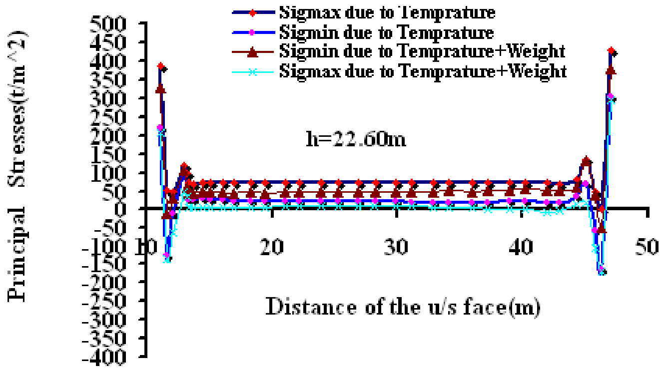

Fig. 8: Variation of principal stresses for lift no 11.

It can be seen from this plot that in the conventional concrete mostly there is tensile stress appears while the core undergoes compressive stresses.

Conclusion:

Based on this study the following conclusion can be drawn:

- Finite element software for the thermal and structural analysis in R.C.C dams exposed to time variables parameters has been developed.
- Disassociating the variation of the thermal characteristics of concrete with respect to stress – strain state of the material allows the study of the problem in a simplified uncoupled way.
- It is possible to consider environmental conditions variability in time, internal heat generation (hydration) and the variability of the geometry during the analysis.
- Tensile stress appears in the skin of the dam, which is at a lower temperature, while the core undergoes compressive stresses.

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