Temperature Distribution in Roller Compacted Concrete RCC Dam Using Two Different Finite Element Codes

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ABSTRACT: A comparative study of temperature distribution in a roller compacted concrete dam during and after construction is carried out using two well known computers codes namely ANSYS and COSMOS. Two and three-dimensional finite element models have been created and analyzed in order to understand and compare the results obtained based on the two computer codes. The influences of the thermal properties and the climatic condition, and the placement schedule of RCC layers were all considered in these analyses. The study demonstrated that the results of temperature computed using ANSYS numerical model analysis is relatively higher and more conservative than the COSMOS results. The available laboratory heat of hydration data and the incremental construction process of mass-concrete structure can be modeled to produce results that can be used in practical applications, in case of Al-Wehdah RCC dam which was used in this study, the maximum temperature which was obtained by ANSYS is higher than the temperature that was obtained by COSMOS by one degree. Furthermore, the thermal results for both 2D and 3D analysis based on the two computer codes are very close to each other. Indicating, thus that there is no need to carry out the 3D finite element analysis to estimate the temperature distribution in the dam body.

KEY WORDS: ANSYS, COSMOS, Finite Element, RCC Dams, Temperature, Thermal Analysis

INTRODUCTION

RCC dams consist of concrete that differs from conventional concrete placed at a lower water-to-cement ratio and it is compacted using equipment and methodologies normally employed for earthfill placement. RCC has gained worldwide acceptance as an alternative to conventional concrete in dam construction due to the construction advantages and proved performance (Luna, et al, 2000). When RCC was first introduced in dam construction, temperature control of RCC placed was not considered, it is because of the amount of cement in RCC being much less than that in the conventional concrete, however, sometimes later, it was discovered that RCC still needs to be monitored since heat produced by the cement could generate thermal stresses which eventually could result in cracks during and/or after the dam construction (Zhu, et al, 1999)..

Mass concrete placement requires precautions to minimize cracking. During the hydration process, cement liberates a substantial amount of heat with a resulting rise of the concrete temperature. It is often reaches about 40-70 °C (Ishikawa M, 1991), after the maximum temperature is reached inside the RCC dam, the latter cools down slowly to a constant temperature. This temperature variation can induce two kinds of problems. First, the heat generated creates temperature gradients between the surface and the RCC core. The resulting nonuniform temperature distribution generates undesired stresses. Second, the reduction of the global concrete temperature to the final equilibrium temperature induces volumetric changes that lead to additional stresses if the mass concrete is externally restrained (Ayotte, et al., 1997). These temperature gradients induce cracks in the structures, which harm their integrity, permeability, and durability.

To find the optimum construction method to avoid thermal cracks numerical simulations using Finite Element Method (i.e. FEM) can be carried out and it can be used to check for cracking. In the numerical simulation, some parameters are assumed, such as heat of hydration produced by the cement, mixed design of concrete, casting schedule, and curing method, etc (Ishikawa M, 1991). Many finite element software packages can be used to predict the heat generated by the concrete, Such as ANSYS, COSMOS/M, ABAQUS and ADINA.

Several techniques are reported in the literature for designers to evaluate the thermal performance of concrete, the structural configuration, and construction requirements. These techniques range from complex three dimensional finite element analysis methods to simple manual computation. Malkawi, et al. (2002) determined the thermal and structural stresses and temperature control requirements for the 60m high Tannur RCC dam in Jordan. Also they study temperature distribution with time, concrete placement temperature limits, and joint spacing requirements to minimize cracking in the Tannur dam. The computer program ANSYS is used and simulates the construction process of the Tannur dam. The actual temperature distribution in the body of the dam also was measured by thermocouples and was compared with that obtained by ANSYS, and generally a good agreement was obtained.

The objective of this paper is to analyze the Al-Wehdah RCC dam using the two commercially available softwares ANSYS and COSMOS/M. The FE 2D and 3D results obtained will be analyzes and discussed. A comparison of the predicted results will be presented and discussed, including the predicted temperature resulting from ANSYS versus the temperature obtained from COSMOS/M.

THERMAL ANALYSIS CONCEPT

Mass concrete is defined by ACI code as "any volume of concrete with dimension large enough to require that measures be taken to cope with generation of heat of hydration of the cement and attendant volume change to minimize cracking." When Portland cement combines with water, the ensuring exothermic (i.e. heat-releasing) chemical reaction causes a temperature rise in concrete mass. The actual temperature rise in a mass concrete structural (MCS) depends upon the heat generating characteristics of the mass concrete mixture, the thermal properties, environment conditions, geometry of MCS, and construction conditions. Usually, the peak temperature is reached in a few days to weeks after placement, followed by a slow reduction in temperature. Over period of several months to several years, the mass eventually cools to some stable temperature, or a stable temperature cycle for thinner structures. A change in volume occurs in the MCS proportional to the temperature change and the coefficient of thermal expansion of the concrete. If volume change is restrained during cooling of the mass, by either the foundation, the previously placed concrete, of the exterior surfaces, sufficient tensile strain can develop to cause cracking. Cracking generally occur in main body or at the surface of the MCS. These two cracking phenomenon are termed mass gradient and surface gradient cracking, respectively. ACI 207.1R contains detailed information on heat generation, volume change, restraint, and cracking in mass concrete.

TEMPERATURE CONTROL REQUIREMENTS

Significant thermal induced stresses are developed as a result of the heat of hydration of the cementitious materials in RCC dams. The temperature distribution through the dam and its evolution with time depend on the following:

- RCC concrete properties,
- Climatic factors,
- Construction procedure,
- Lifts Thickness, and
- Initial temperature of the lifts, and the interval between their placements.

These thermally induced stresses can be significant enough to induce cracks in the RCC. Recent developments in sophisticated software based on advanced numerical methods, together with the continually increasing power of computers allow complex analyses for such thermal-structural problems to be calculated.

THE FINITE ELEMENT CODES

The two available finite element commercial codes i.e. COSMOS and ANSYS are used to carry out the thermal analysis for AL-Wehdah RCC dam.

COSMOS

The COSMOS code is fast, robust, and accurate finite element program for analyzing linear and nonlinear steady state and transient heat conduction problems with convective and radiative type boundary conditions in one, two, and three-dimensional geometries (Structural Research and Analysis Corporation , 1997).

Time curves facility is the most important option in the COSMOS program; it enables the user to simulate any dependent time problems. For example, many parameter in our model is time dependent; RCC casting, heat generation due to the heat of hydration of RCC, and convection… etc. Killing and living the elements are also done using the time curve option. Figure 1 shows all the time curves that were used in model analysis. For the first layer as shown, the heat generation started from time zero, while for the next layer, zero values were given to the heat generation until the placement time reached for this layer. The same thing is done to apply the heat convection on the layer surface, this convection continuing for ten days only, so a time curves with zero values are made and a value of one (1) for 10 days only is given to the time curve to alive the convection on this layer, the convection on the outer surface will start when the layer placed but this convection will continue, so the value (1) will extend from the placement to the last time as shown.

ANSYS

The finite element program ANSYS has many capabilities, ranging from a simple, linear, static analysis to complex, nonlinear, transient dynamic analysis. The basis of thermal analysis in ANSYS is a heat balance equation obtained from the principal of energy conservation. The finite element solution you perform via ANSYS calculates nodal temperature, and then uses the nodal temperature to obtain other thermal quantities (ANSYS 5.4 User's Manual).

Birth and death of elements procedure is one of the most important and effective facilities in ANSYS program. It is used to simulate any dependent time problems. For heat convection boundaries for instance, a convection boundary condition should be superimposed on the surface of conduction element when ANSYS is used. In the process of adding the concrete, 'birth' should be given to the heat conduction elements that correspond to the concrete, the heat convection boundary condition are also given 'birth', that means applying convection on the top of conduction element at the same time if the conduction elements include heat convection boundaries. However, the element which was previously given the operation of 'birth', should not be given the 'death' operation in any of the following steps; this operation is shown in Fig. 6 which shows such operation from STEP i to STEP i+1. Either the 'birth' or 'death' is given only one time. In this way, the analysis can be done with a single computational mesh instead of several ones, one for each stage of construction.

AL-Wehdah RCC Dam

AL-Wehdah dam will be built on the Yarmouk River near the Maqarin Railroad Station. The dam will regulate the stream flow of the Yarmouk River to provide enough water for irrigation in the Jordan Valley and for municipal and industrial supplies to the Amman/Zarqa area. Al-Wehdah dam will be built as a Roller Compacted Concrete (RCC) gravity dam of about 96m high with crest at elevation 110 m ASL. The total storage capacity is about 110 MCM at elevation 110 m ASL. AL-Wehdah dam is situated about 26 km east of the Jordan Rift Valley. The upstream face of the dam is vertical with a batter at 1:0.6 from El 65 to foundation level; the stepped downstream slope is at 0.8:1 (Figure 3).

MODELING

The numeric modeling of the 96 meter high AL Wehdah dam is based on the information obtained from the literature and the field, this includes: the daily ambient temperature, the temperature of the RCC in unsettled initial stage, the adiabatic increment curve of temperature, thermal conductivity, specific heat, density of the RCC, the bedding mix., and the placement temperature of the concrete.

PRINCIPAL ASSUMPTIONS

The analysis considered some simplifying assumptions related to factors that should affect thermal variations.

The model divided the RCC dam into 32 layers, each layer was 3 m high and constructed in 10 days while according to the actual method of construction, the layer is 30 cm high constructed each day. Placing lifts every ten days results in higher temperatures since the new lift adds heat to the previous lift before a significant amount of cooling can occur. The temperature of the convective medium, the air, is the mean daily ambient temperature that is a function of time and represents the project site conditions. A mean daily temperature is used because of the difficulty in predicting changes in the temperature variations throughout the day and to alleviate the need for an excessive number of time steps.

The analysis is carried out considering plain strain linear elastic behavior, simplified soil-structure interaction entailing elastic foundation and a uniform, homogeneous foundation, a uniform placement temperature, and a uniform convection coefficient to all layers.

MODEL PROPERTIES AND PARAMETERS

Cementitious Materials

The analysis is based on an RCC mixture containing 60 kg/m^3 of Portland cement and 30 kg/m^3 of Jordanian pozzolan. The calculated heat of hydration obtained from Jordanian pozzolan is about 20% of the cement heat of hydration.

Concrete Placement Temperature

The temperature of concrete aggregate has the greatest influence on the initial temperature of the fresh RCC. Due to the low volume of mix water and the minor temperature difference of the water compared to the aggregate, the water temperature has a much less significant effect on the overall temperature. Table 1 provides the basis for estimating aggregate temperature and approximating the RCC placing temperature used in the analysis. Since aggregate production will be done concurrently with the RCC placement, stockpile temperatures should closely parallel the average monthly ambient temperatures. Some heat is added because of screening, crushing, and transportation activities. In practice, that temperature may vary from one layer to the other because of being exposed to the sun. The average monthly ambient air temperature is shown in Table 1, RCC placement was assumed to take place in the hot months of the year i.e., from June to the end of September. Based on the average ambient air temperature from June to September of 28.25^o C, an average RCC placement temperature of 28.^{o} C was adopted.

Materiel Properties and Environmental Conditions

The model properties used were assessed from available data and typical RCC properties. The density, modulus, Poisson ratio, specific heat and thermal conductivity are given in Table 2. A convection coefficient for air was used, which is consistent with moderate wind speed.

The thermal expansion coefficient is another properties used in analysis on thermal stress in concrete. A typical coefficient of thermal expansion of 8.6x10^{-6} /°C was adopted for the concrete. The thermal behavior of the RCC dam was modeled by considering the heat generated by the exothermic reaction of the cement paste during the cure. The heat transfers by conduction in the concrete mass and the rock, as well as the convection on the faces exposed to ambient temperature were considered.

Heat of hydration

During the hydration of cementations materials, numerous factors and interaction are involved, some of which are currently not fully understood. As part of this study, a different cementations materials and mixture proportions that give a different heat of hydration are used. Heat generation rates adopted for the 60 kg/m^3 cement plus 30 kg/m^3 pozzolanic material were based on the heat of hydration of the Jordanian Ordinary Portland Cement (OPC) plus that of pozzolanic material. A heat of hydration of 405 J/g at 28 days was adopted and used in the thermal analysis see Figure 5, Figure 6 shows the heat of hydration for finite element analysis for the Jordanian pozzolan material.

BOUNDARY AND INITIAL CONDITIONS

Figure 4 shows the boundary and initial conditions for thermal and structural analysis, which are:

1. All boundaries around the foundation rock satisfy the adiabatic condition: $\partial T/\partial n = 0.0$ (i.e., no change in temperature in the direction normal to the planes. The dam and foundation that are exposed to the atmosphere satisfy the following condition (as defined previously).

   $$K(\partial T/\partial n) = -h_f (T - T_B) \qquad (1)$$

   Where T is the transient temperature, n the outer unit normal, K is the thermal conductivity, h_f is the film coefficient and T_B is ambient temperature.
2. Initial condition. The initial temperature for all nodes of foundation is assigned from rock temperature. The initial temperature of each layer of the dam is set to be equal to the placement temperature.

MODEL ANALYSIS

Two and Three Dimensions Model Analysis using COSMOS

The dam was modeled as a two-dimensional transient heat transfer model to simulate the real construction process of the dam. The time curve option in the COSMOS/M Program that was discussed previously is used for the heat of hydration in the dam body and the heat convection effects to simulate the time lag between the placements of the RCC layers. The dam is divided into 32 layers. Each layer has thickness of 3 m constructed in 10 days. The total number of elements and nodes are 2266 and 7074 respectively. Quadrilateral plane element with eight nodes was used in the finite element analysis (Figure 7). The element has one degree of freedom temperature at each node. This is a high order element that has 8 nodes, is suitable for simulating irregular shapes, and is applicable to the study of a two-dimension steady state or transient thermal analysis. A 3-D analysis was also carried out for Al Wehdah RCC dam. The length of the dam is divided into 16 blocks, each block 30 m long, the total number of elements and nodes is 11330 and 14424 respectively. A solid element type was used for the thermal analysis (see Fig 7). This element has 8 nodes with a single degree of freedom temperature at each node; Figure 9 shows the finite element mesh of 2D and 3D cross section of dam.

Two and Three Dimensions Model Analysis using ANSYS

The dam was modeled as a two-dimensional transient heat transfer model using a birth and death procedure to simulate the real construction process of the dam. The dam is divided into 32 layers. Each layer has thickness of 3 m constructed in 10 days; the rock foundation is presented from 30 meters upstream, 30 meters downstream and 30 meters under the dam. The rock elements simulate the heat dissipation through the foundation, the total number of elements and nodes are 2266 and 7074 respectively. PLANE77 element type available in ANSYS element library was used. The element has one degree of freedom temperature at each node as shown in Figure 8. This element is a higher order element has 8 nodes and it is suitable to simulate irregular shape and applicable to a two dimension steady – state or transient thermal analysis. A plane strain model was adopted for two-dimension analysis. A 3-D analysis was also carried out for Al

Wehdah RCC dam. The length of the dam is divided into 16 blocks, each block 30 m long. A solid 70 element type was used for the thermal analysis, Figure 8. This element has 8 nodes with a single degree of freedom temperature at each node. Same procedure in two dimensions was used for three dimensions to generate the mesh. The total number of elements and nodes is 11330 and 14424 respectively. The step-by-step analysis of the construction simulation process allows the determination of the temperature for each added lift, Figure 10 shows the finite element mesh of 2D and 3D cross section of dam.

FINITE ELEMENT RESULTS

Finite Element Results of COSMOS

Figure 11 shows the temperature contours in the dam body after 100 days for a placement temperature of 28°C and for RCC mix containing Jordanian pozzolan using two and three dimensional analysis, it can be seen that the maximum temperature in the dam core is 42.34 °C for 2D analysis and 43.17 °C for 3D analysis. At the end of heat of hydration as shown in Figure 12 the temperature decreased to 42°C and 42.2°C for 2D and 3D analysis respectively.

The temperature distribution shown in Figure 15 is for a specific points located at a distance 12m from the dam base at different distance from the dam upstream, once the RCC placed the temperature drop quickly to 23.2°C due to the convection on the layer surface then the temperature rise to 42.3°C for two dimensional analysis, the drop in 3D analysis was 23.1°C and the maximum reached temperature was 42.6°C.

Figure 17 shows the predicted temperature history in the dam center at different heights, this figure determines the elevation where the maximum temperature was occurred. For 2D analysis as shown, 42.3 °C is the maximum temperature that can occur in the dam during the construction; it is at 12 m from the dam base. While in 3D analysis the peak temperature was 42.6 °C at the same elevation.

Finite Element Results of ANSYS

Figure 13 shows the temperature contours in the dam body after 100 days for a placement temperature of 28°C and for RCC mix containing Jordanian Pozzolan using two and three dimensional analysis, it can be seen that the maximum temperature in the dam core is 43.6 °C for 2D analysis and 43.6 °C for 3D analysis. At the end of heat of hydration as shown in Figure 14 the temperature was 43.7°C and 43.9°C for 2D and 3D analysis, respectively.

The temperature distribution shown in Figure 16 is for a specific points located at a distance 12m from the dam base at different distance from the dam upstream, once the RCC placed the temperature drop quickly to 24.1°C due to the convection on the layer surface then the temperature rise to 43.7°C for two dimensional analysis, the drop in 3D analysis was 24.1°C and the maximum reached temperature was also 43.9°C.

Figure 18 shows the predicted temperature history in the dam center at different heights, this figure determines the elevation where the maximum temperature occurs. For 2D and 3D analysis, 43.9 °C is the maximum temperature that can occur in the dam during the construction; it is at 12 m from the dam base.

SUMMARY AND DISCUSSION

Table 3 summarizes the models analysis for both COSMOS and ANSYS codes, also it summarizes the results that were obtained from these programs and then the crack analysis for these results is also summarized.

Figures 19 and 20 show the predicted temperature history using two and three dimensional analysis by ANSYS and COSMOS at a nodal point in the dam center and at a point near the upstream face; both points are at 12 m from the dam base.

Figure 21 shows the temperature distribution along the dam cross section at an elevation of 22 m from the dam base using two and three dimensional analysis by ANSYS and COSMOS at the end of heat of hydration (410 Days).

Figure 22 shows the vertical temperature distribution at the dam center at the end of heat of hydration using also the two and three-dimensional analysis. It is clearly seen that both two and three dimension analysis gave nearly the same results, for both COSMOS and ANSYS, so discussing one of these analysis will be enough.

From all of these figures, it can be seen that the maximum temperature obtained from ANSYS program are higher than that obtained from COSMOS by nearly one degree.

Since the two meshes for ANSYS and COSMOS has the same number of elements and nodes, and the same material properties applied on both of them, it can be concluded that this difference in temperature may occur due to two factors, the first is the heat generation due to the heat of hydration, and the other is the temperature drop due to the convection effects.

The values of heat of hydration at each 10 days were used in the two programs according to Figure 6, but 1 day increment was used, the heat of hydration at this increment was interpolated by the programs, the interpolation process that is done by COSMOS differs from the ANSYS interpolation. Once the RCC placed, the temperature dropped from 28°C to 23°C in COSMOS analysis, while it dropped to 24°C in ANSYS as shown in Figure 19, this is one of the factors that affect the maximum temperature results. This difference refers to the theories that each code is based on.

From the crack analysis presented in Table 3, it can be concluded that ANSYS gives more conservative results; 42 contraction joints must be placed according to ANSYS results while 40 contraction joints is enough according to COSMOS results.

CONCLUSIONS

The following conclusions may be drawn;

1. Thermal analysis is one of the most important analysis that should be done for the RCC dam to provide the engineer with a means of predicting excessive tensile stresses and strains, which could indicate possible cracking, therefore, allowing the designer to take appropriate measures to limit or control such potential cracks
2. Finite element models is becoming an increasingly powerful tool for civil engineers to more accurately predict behavior of unprecedented structures for which limited experience is available, such as RCC dams.
3. Using a commercially available finite element program such as ANSYS and COSMOS and the available laboratory data, the incremental construction process of mass-concrete structure can be modeled to produce results that can be used in practical applications
4. The thermal results that obtained from ANSYS are more conservative than the COSMOS results, the maximum temperatures which were obtained by ANSYS are higher than the temperatures obtained by COSMOS by one degree.
5. The thermal results for both 2D and 3D analysis are very close to each other. So there is no need to carry out 3D finite element analysis to estimate the temperature distribution in the dam body.
6. The temperature in the interior of a RCC gravity dam drops very slowly, cracks may appear on the upstream and downstream face especially in the winter, thus some measures must be taken to prevent these cracks. The most effective measure is to insulate the concrete surface.

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Table 1 Predicted RCC Placement Temperatures

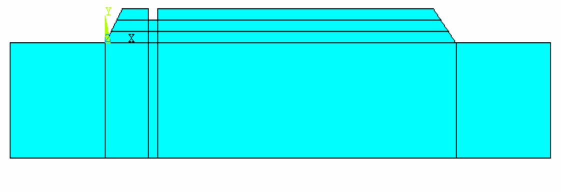
Month	Mean Monthly Temp (°C)	Mean Annual (°C)	Diff (°C)	2/3 Diff (°C)	Sub Total (°C)	Aggregate Crushing Add (°C)	Aggregate Stocking Temp (°C)	Mixing Add (°C)	Trans. Add (°C)	Final Temp (°C)
Jan.	12.3	21.2	-8.9	-5.93	15.27	1.2	16.47	1.2	-0.6	17.07
Feb.	12.8	21.2	-8.4	-5.60	15.60	1.2	16.80	1.2	0	18.00
Mar.	15.6	21.2	-5.6	-3.73	17.47	1.2	18.67	1.2	0.6	20.47
Apr.	20.6	21.2	-0.6	-0.40	20.80	1.2	22.00	1.2	0.6	23.80
May	24	21.2	2.8	1.87	23.07	1.2	24.27	1.2	1.1	26.57
Jun.	26.7	21.2	5.5	3.67	24.87	1.2	26.07	1.2	1.1	28.37
Jul.	28.4	21.2	7.2	4.80	26.00	1.2	27.20	1.2	1.7	30.10
Aug.	30.1	21.2	8.9	5.93	27.13	1.2	28.33	1.2	1.7	31.23
Sep.	27.8	21.2	6.6	4.40	25.60	1.2	26.80	1.2	1.1	29.10
Oct.	24.5	21.2	3.3	2.20	23.40	1.2	24.60	1.2	0.6	26.40
Nov.	19	21.2	-2.2	-1.47	19.73	1.2	20.93	1.2	0	22.13
Dec.	14	21.2	-7.2	-4.80	16.40	1.2	17.60	1.2	-0.6	18.20
Average										24.4

Table 2 Properties Adopted for Thermal Analysis

Roller Compacted Concrete	
Density	2450 kg/m^3
Coeff. of Thermal Expansion	8.6 E-6 /deg C
Specific Heat	920 J/kg deg C
Thermal Conductivity	2.15 J/s m deg C
Film (convection) Coefficient	15 J/s m^2
Heat Generation of RCC	405 J/g at 28 days
Placement Temperature	28° C
Modulus of Elasticity	10.0 GPa
Rock Foundation	
Density	2600 kg/m^3
Coeff. of Thermal Expansion	6.0 E-6 /deg C
Specific Heat	900 J/kg deg C
Thermal Conductivity	2.15 J/s m deg C
Foundation Rock Temperature	21.3°
Modulus of Elasticity	4.9 GPa

Table 3 Summary Results for COSMOS and ANSYS

DESCRIPTIONS		**COSMOS**		**ASNYS**	
		2D	**3D**	**2D**	**3D**
General	Output file size (GB)	0.24	1.6	0.14	0.72
	Run Time (hr)	1	4	0.5	3
Model Analysis	No. of Elements	2266	11330	2266	11330
	No. of Nodes	7074	14424	7074	14424
	Element Type	Plane 2D	Solid	Plane 77	Plane 70
	Time Simulation	Time Curves		Birth & Death	
Results	Peak Temperature	42.3	42.6	43.6	43.8
	Elevation of Peak Temp (m)	12	12	12	12
	Time of Peak Temp (days)	110	110	110	110
	Temp. Drop due to Convection ^{o}C	23.2	23.1	24.2	24.1
Crack Analysis	$\Delta T\,^{o}$C	30.3	30.5	31.2	31.5
	Induce strain (μmm)	142	143	148	149
	No. of block	40	40	42	43
	Length of block (m)	26	24	23	23



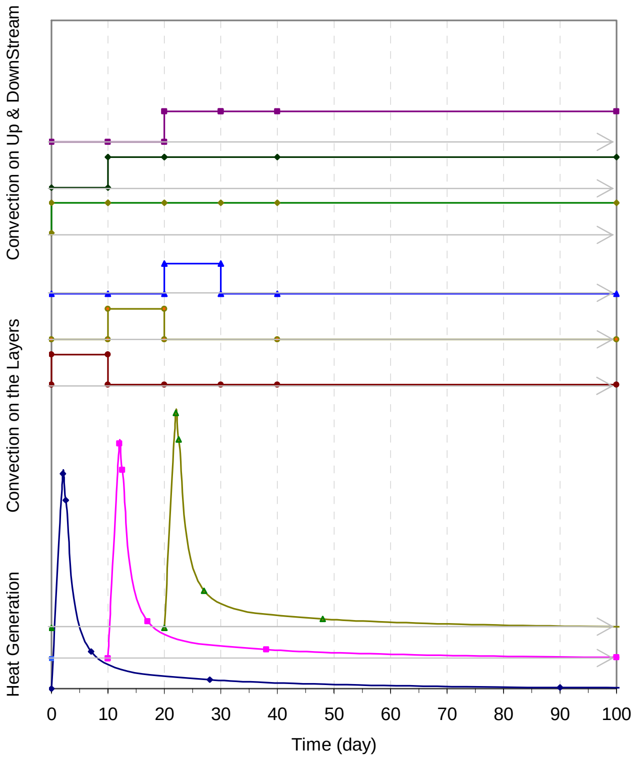


Fig 1 Time Curves Used in COSMOS/M for the 1st three layers.

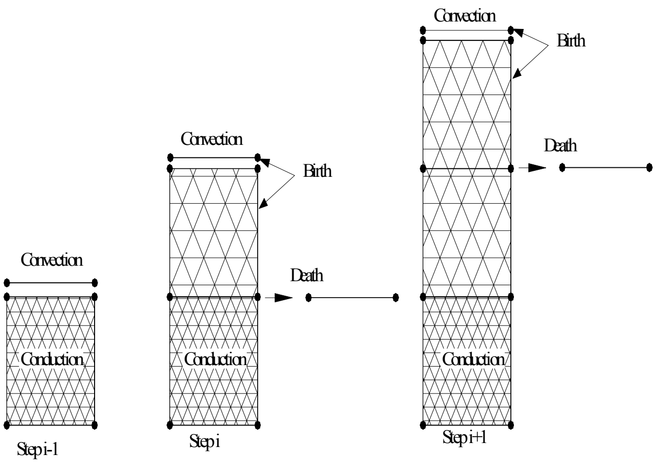


Fig 2 Births and Death of Elements.

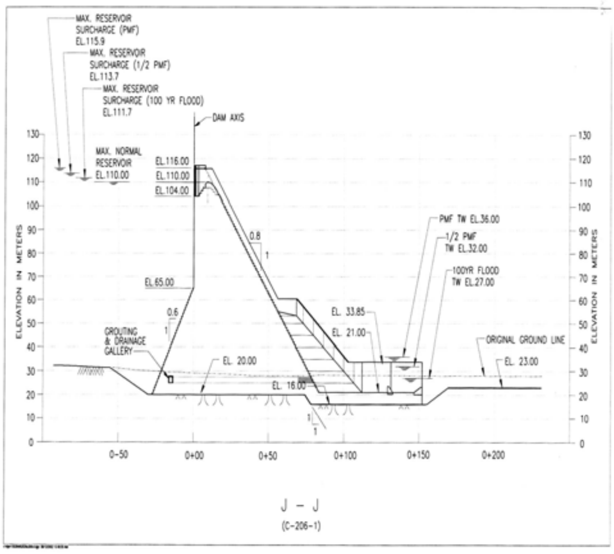


Fig. 3 Typical Cross Section for Al-Wehdah Dam.

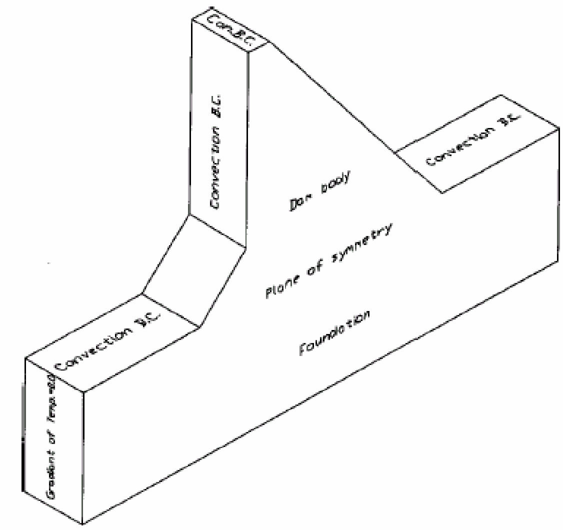


Fig 4 Thermal and Structure Boundary Conditions for Thermal Analysis.

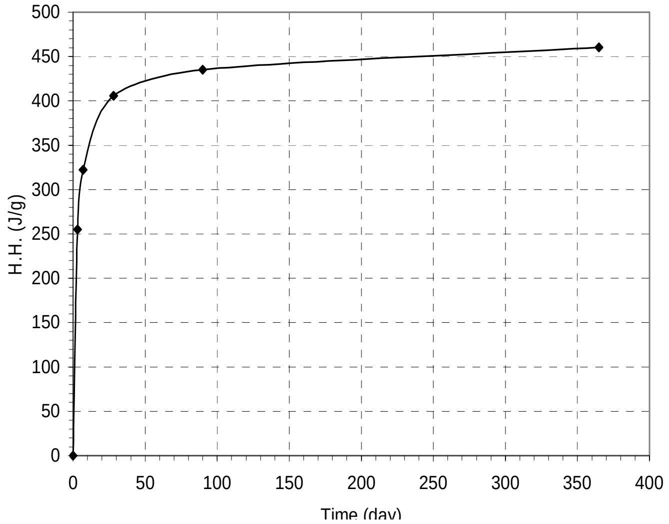


Fig5. The Accumulative Heat of Hydration of the Cement (OPC).

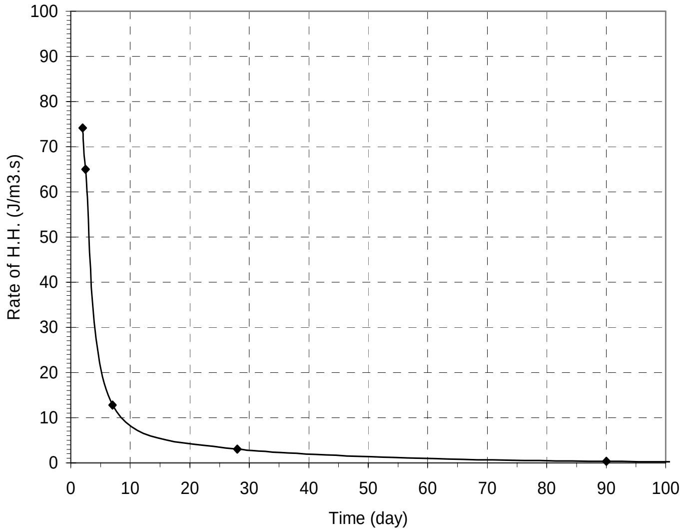


Fig 6 Heat of Hydration for RCC mix (60 kg/m^3 Cement, and 30 kg/m^3 Jordanian pozzolan), for Finite Element Analysis.

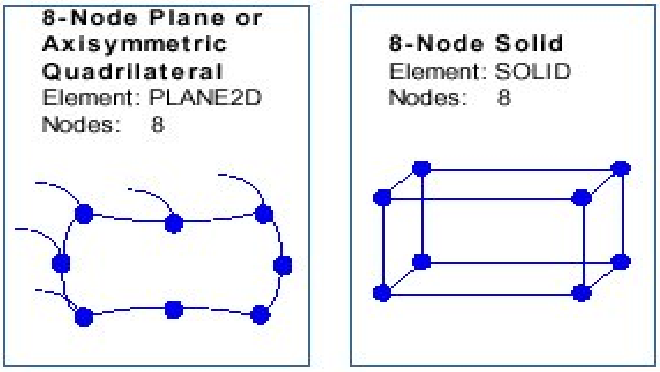


Fig. 7 Element Types Used in COSMOS.

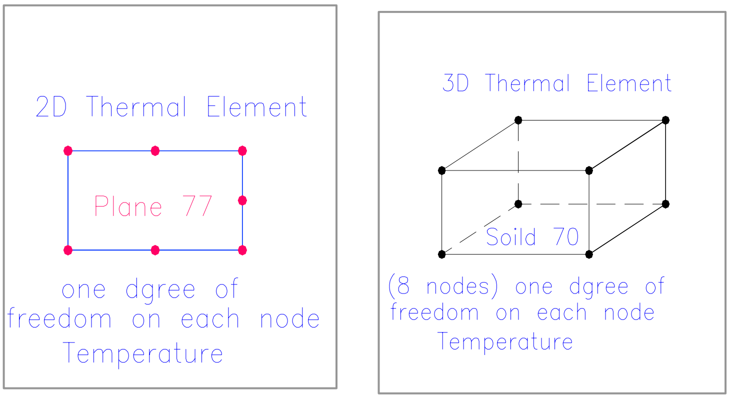


Fig. 8 Element Types Used in ANSYS.

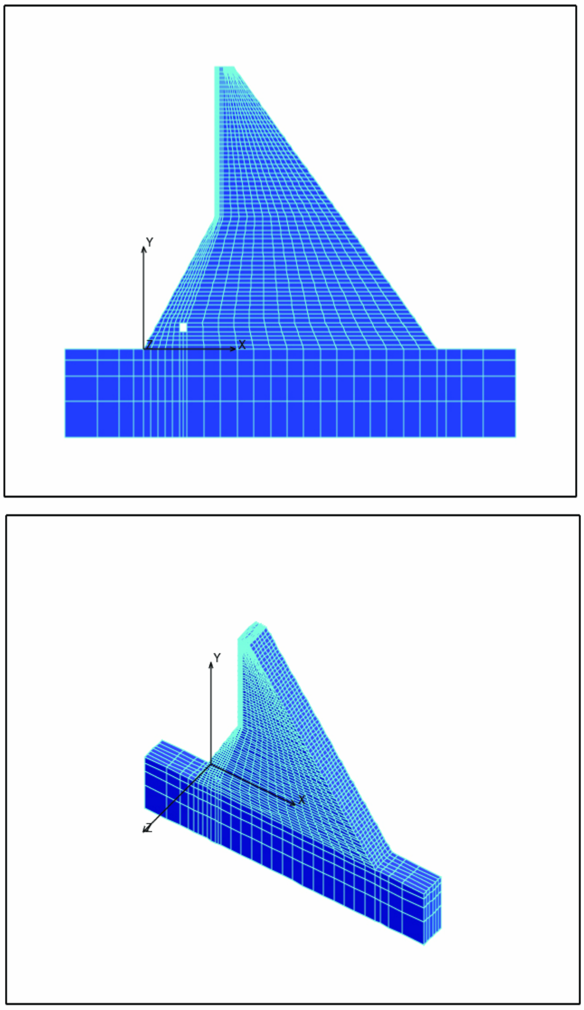


Fig. 9 Two and Three Dimension Model Mesh in COSMOS.

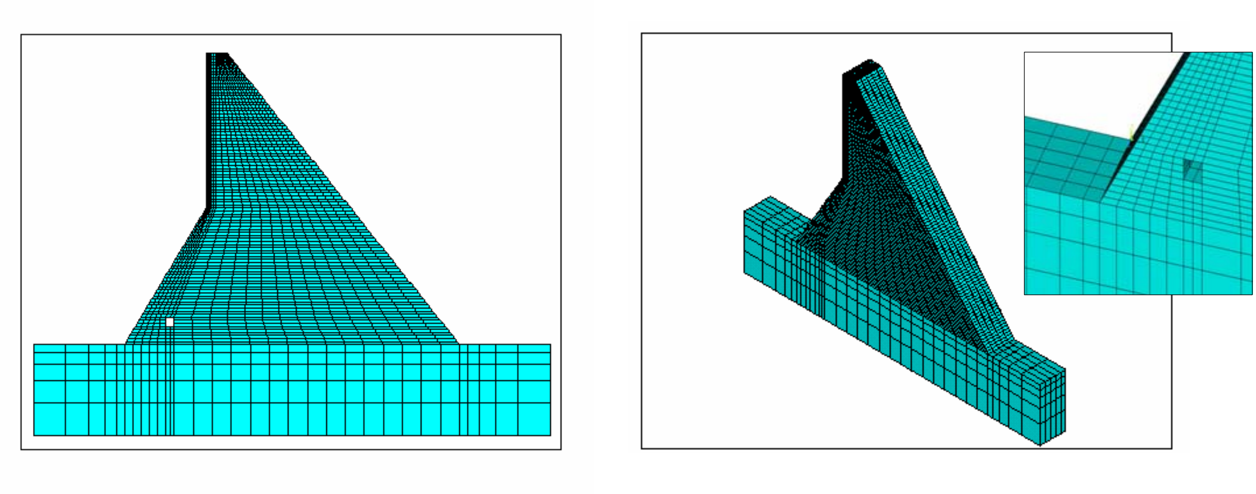


Fig. 10 Three Dimension Model Mesh in ANSYS.

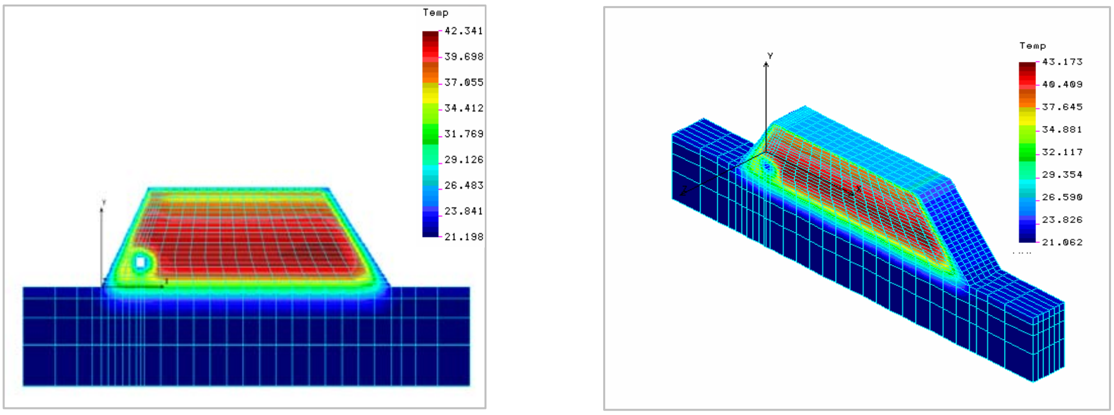


Fig 11 Temperature Contour after 100 days using COSMOS.

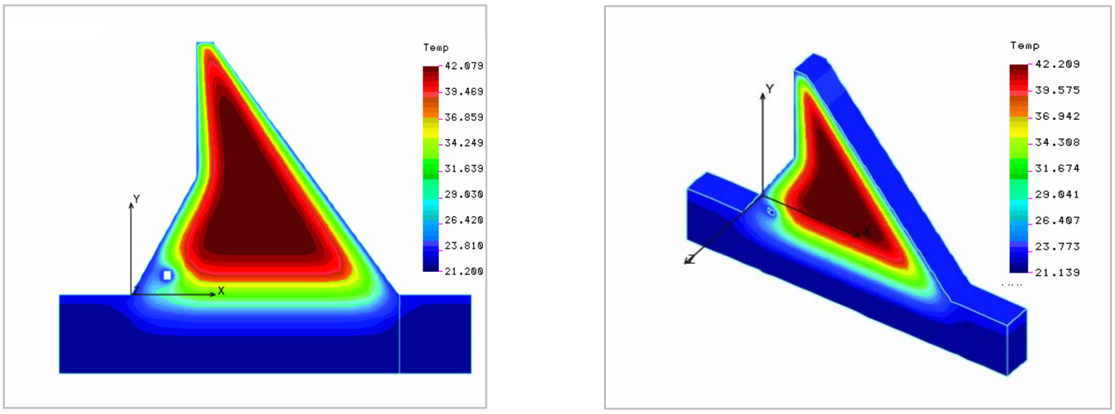


Fig 12 Temperature Contour at the End of Heat of Hydration, 410 days using COSMOS.

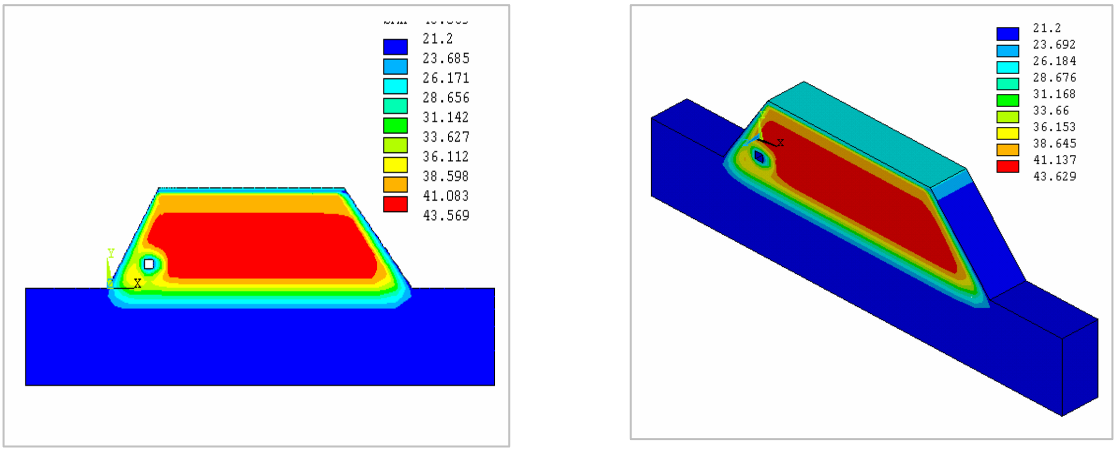


Fig 13 Temperature Contour after 100 days using ANSYS.

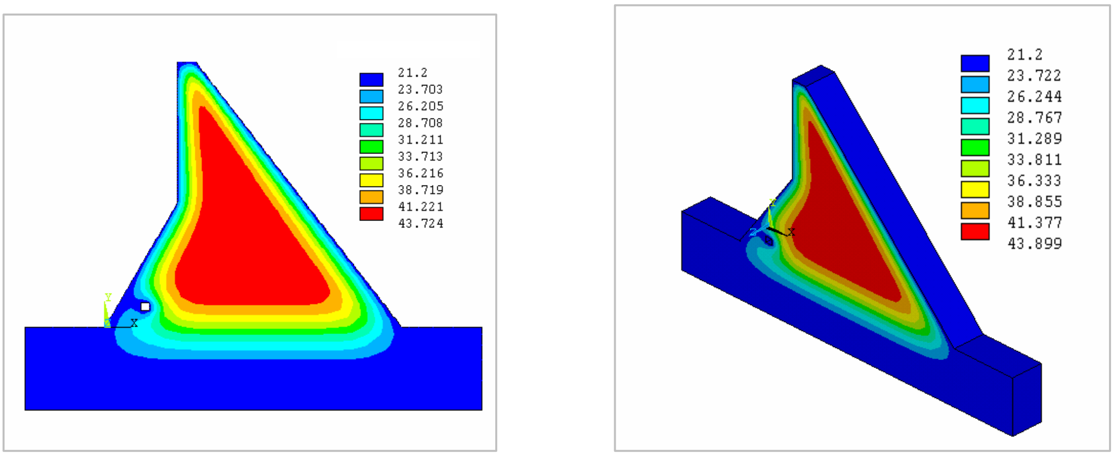


Fig 14 Temperature Contour at the End of Heat of Hydration, 410 days, using ANSYS.

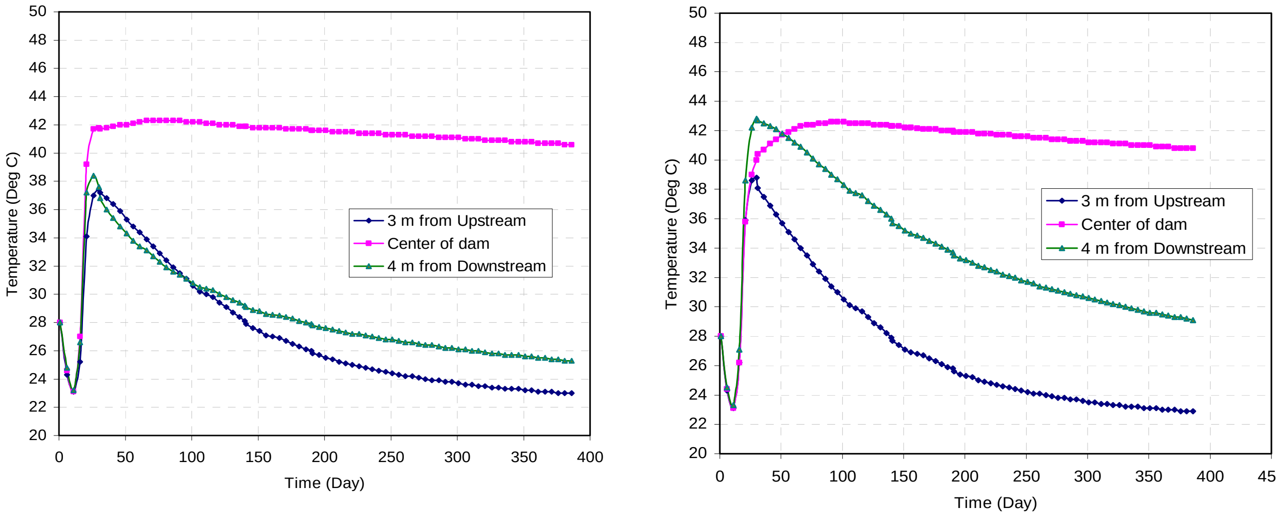


Fig 15 Predicted Temperature History at Different Nodal Point at 12m from the Dam Base using COSMOS for 2D & 3D.

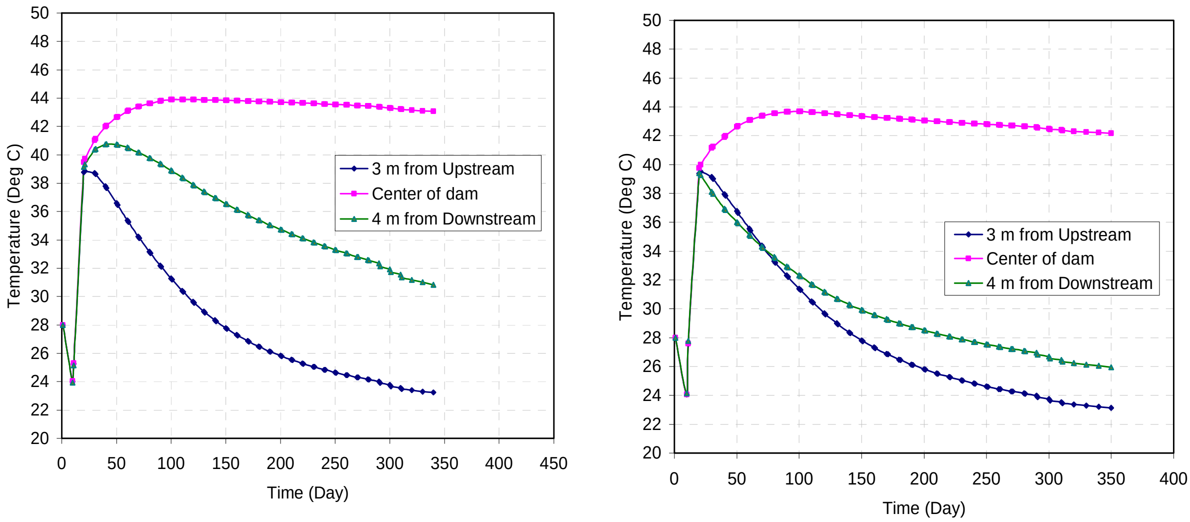


Fig 16 Predicted Temperature History at Different Nodal Point at 12m from the Dam Base using ANSYS for 2D & 3D Analysis, respectively.

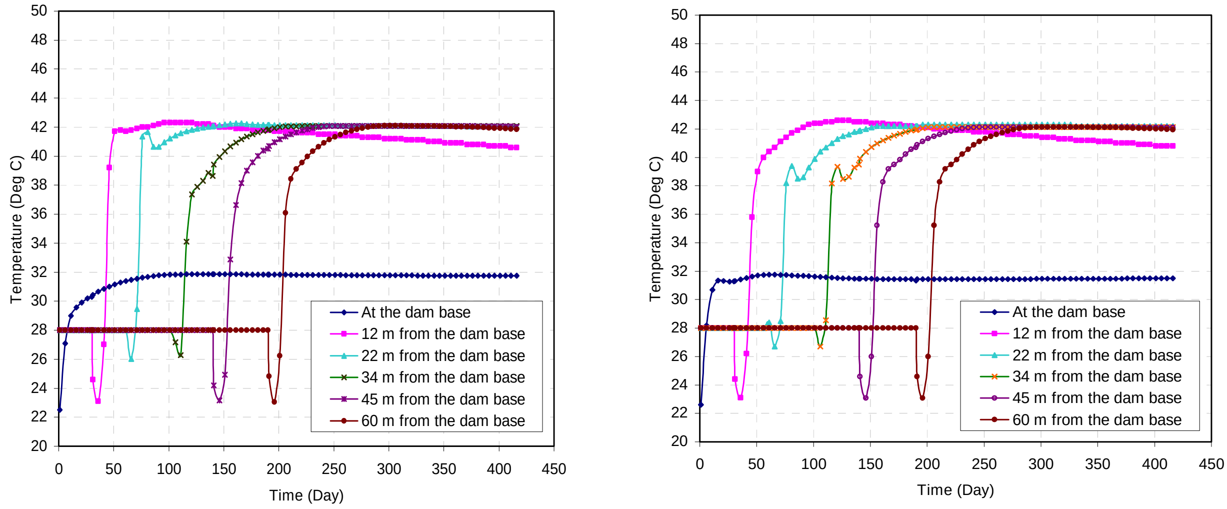


Fig 17 Predicted Temperature History in the Dam Center at Different Heights using COSMOS for 2D & 3D Analysis, respectively.

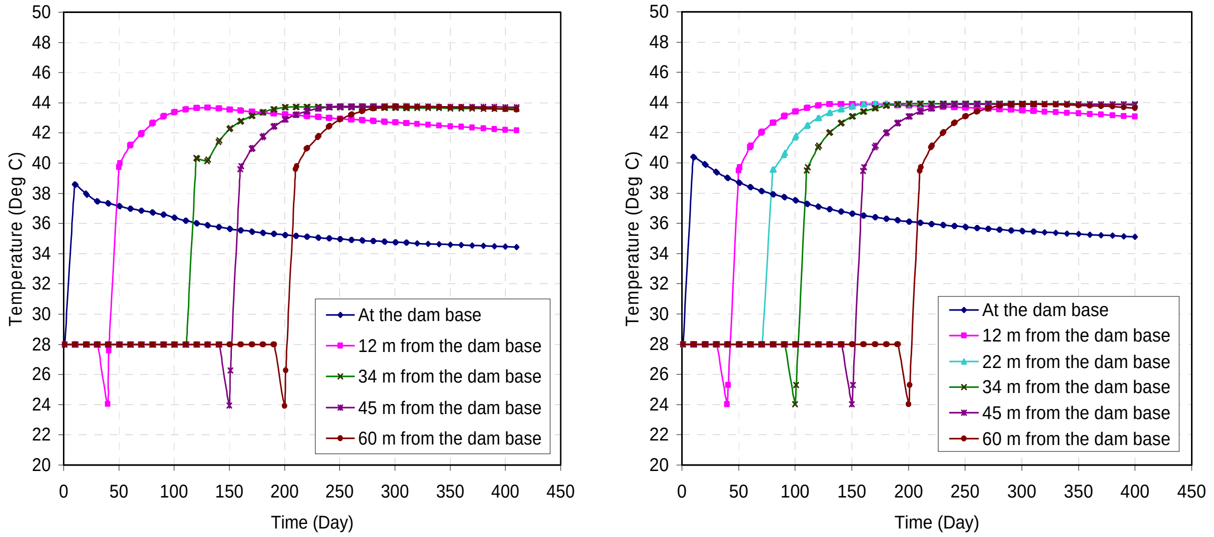


Fig 18 Predicted Temperature History in the Dam Center at Different Heights using ANSYS for 2D & 3D.

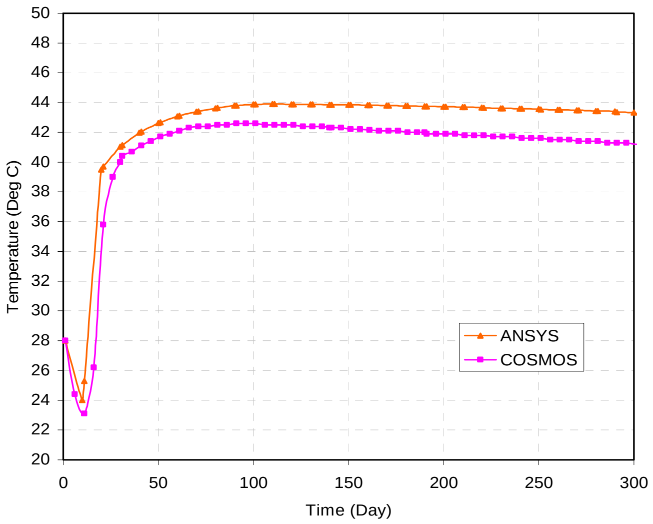


Fig 19 Comparative Predicted Temperature History using ANSYS and COSMOS at the Dam Center and 12 m from the Dam Base using 3D Analysis.

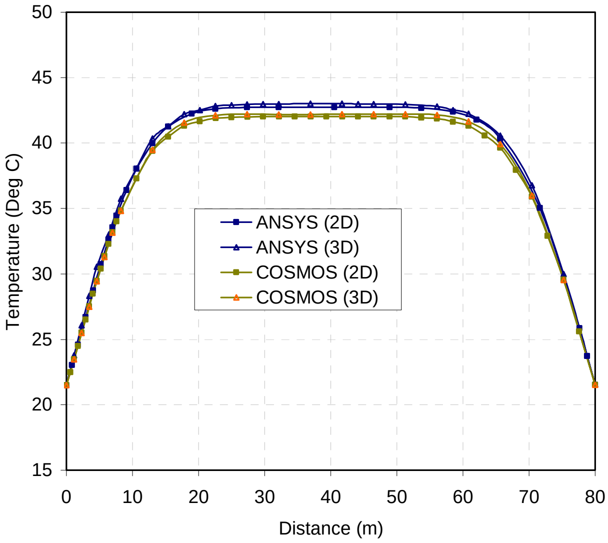


Fig 21 Cross Section Temperature Distribution at 22 m from the Dam Base using ANSYS and COSMOS.

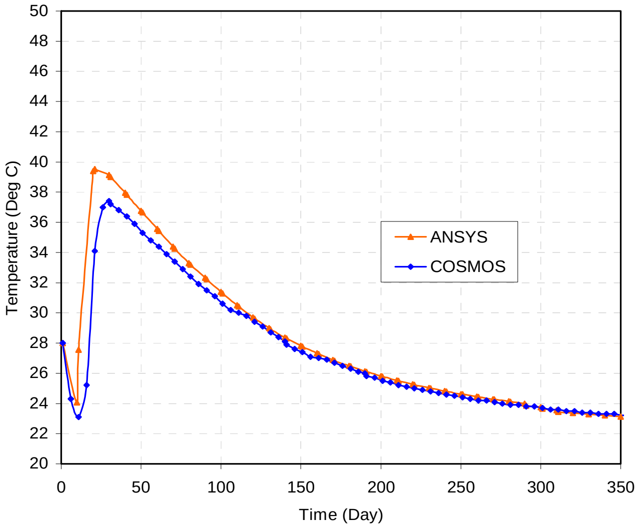


Fig 20 Comparative Predicted Temperature History using ANSYS and COSMOS at 3m from Upstream and 12 m from the Dam Base using 2D Analysis.

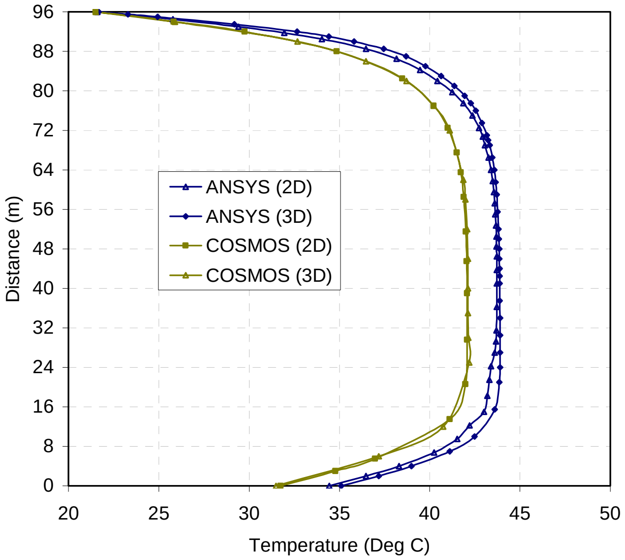


Fig 22 Vertical Temperature Distribution at the Dam Center using ANSYS and COSMOS.