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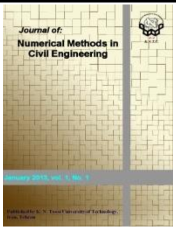

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Optimization of time and temperature of dam construction for thermal analysis of roller-compacted concrete dam

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Abstract:

The growing number of roller-compacted concrete dams built worldwide demand suitable methods to reduce the risk of thermal cracks. In roller-compacted concrete dams, large amounts of concrete are usually poured in a short time, and the heat generated by the hydration of the cement leads to an increase in temperature in the body of the dam, which results in a significant heat slope. In this research, the Abaqus finite element software was used for thermal analysis of the dam during construction and concreting. The method of applying thermal changes is as follows: Hypothetical 50-cm layers are considered for the structure, with each layer taking up 72 hours of analysis time. In general, the problem under analysis is analyzed 12 times. Each analysis is based on the start of the project in different months of the year to achieve the optimal construction time based on the maximum temperature in the dam's concrete and the stresses created by it by collecting the information and using the Perceptron network algorithm. The Perceptron algorithm and machine learning were performed on the 12 mentioned analyses, and then the process output was generated for 365 days of the year as the start of the project. Finally, the optimal time to start construction was obtained.

1. Introduction

Concrete is the most widely used material globally and forms a wide range of building structures, offshore structures, bridges, tunnels, dams, and pavements. On the other hand, infrastructure construction has expanded sharply in recent decades, and concrete structures have a significant share. Advances in bulk concrete technology to reduce the percentage of cement have led to the emergence of the roller-compacted concrete method. The roller-compacted concrete allows for higher speeds than conventional concrete, which has economic benefits such as cost-saving per unit volume of concrete and significantly reducing construction time and shuttering. This type of concrete is very suitable in places where it is possible to concrete a layer with a high ratio of surface to thickness. As an example, the use of this type of concrete in dams and roads can be mentioned.

Roller-compacted concrete is a new method for the economical construction of bulk structures such as gravity dams. In this type of concrete, a combination of features of the concrete and soil technology is used, and it is transported, spread, and compacted by using machines for constructing embankment dams. Therefore, concreting is faster, and execution costs are significantly reduced. By definition, roller-compacted concrete is concrete with zero slump, and earthworks machinery is used to transport, spread, and compact it. The main advantage of this type of concrete is its low cost. Therefore, the roller-compacted concrete should be dry enough to be easily spread like soil grains and compacted by compactor machines such as rollers. On the other hand, to create adhesion between the aggregates, it must be moist enough that concrete sap can provide the necessary coating for all aggregates.

Therefore, rolled concrete in the un-compacted state is very different from ordinary concrete. There is no concrete sap in the mixture, and it acts like soil materials, but after compaction and hardening, it will behave like ordinary

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concrete (with a similar ratio of water to cement). The properties of concrete are considered as a function of time. So, if the dam is constructed in the cold seasons, the maximum temperature of the dam will decrease. The temperature of concrete due to the high heat produced during the hydration reaction of cement in bulk structures and the effect of environmental factors and volumetric changes in the structure causes tensile stresses in concrete. The presence of a limiting factor that resists the reduction of concrete volume due to shrinkage is the most critical factor in creating tensile stress and cracking in dams. Due to the importance of thermal analysis of dams, many studies have been conducted to simulate their thermal during the construction and operation [1]

The risk of thermal cracking in dams has been investigated using finite element modeling. In a study, heat production and distribution in bulk concrete were investigated, and by examining the process of creating thermal stresses and the factors affecting them, methods of controlling thermal stresses such as the use of pre-cooling pipes were evaluated. The results showed the effect of pre-cooling and post-cooling in controlling thermal cracking [2]. Thermal analysis of concrete gravity dam was performed using the Adina software. Due to the relationship between the modulus of elasticity of concrete and time, the temperature distribution trend of heat stresses was investigated using the finite element method. A time-dependent exponential function was used to calculate the heat generated by hydration and the rate of increase of adiabatic temperature. [3].

Investigation of temperature distribution in the body of gravity concrete dams and thermal analysis for roller-compacted concrete dams to investigate their thermal response using the ANSYS software is among the studies performed [4]. A three-dimensional numerical model considering the viscoelastic nonlinear behavior of a concrete gravity dam was presented and compared with the actual behavior of the dam. The results from the proposed model showed a good agreement with the actual behavior of the dam in terms of stress and crack distribution. In the following studies, the direction of crack propagation in a roller-compacted concrete dam was investigated, and it was shown that the most critical situation for crack propagation is along the axis of the dam [5].

Changes in thermal stresses and distribution of stresses in Kinta Dam have been studied after construction and during operation, and it has been shown that thermal stresses increase during operation, but their position and distribution process is usually similar. The results of studies show that one of the problems in modeling a dam system for thermal analysis is constantly applying the ambient temperature in proportion to the time of concreting. So far, in many modeling, the effect of ambient temperature has been considered as a constant number, which is not the case in reality, and each layer of concreting has its environmental conditions [6].

Modal identification is a type of system identification that studies the modal parameters of systems by using the modal test. In another study, a fully automated operational modal identification algorithm was developed to identify modal parameters of an arch dam. For this purpose, Morrow point arch dam was selected, and a 3-D finite element of the dam was established. The results indicated acceptable identification via the proposed algorithm using a dataset and non-repetitive data acquisition. Moreover, the identification process was automated and did not require user interaction. It is noteworthy that this algorithm can identify any dam with any number of mode shapes and is practical and straightforward to apply. [7].

Investigation of the stability of arch dam abutments is one of the most important aspects of analyzing such dams. To this end, in another work, the Bakhtiari dam, a doubly curved arch dam with six wedges at each of its abutments, was selected. The seismic safety of dam abutments was studied through time history analysis using the design-based earthquake (DBE) and maximum credible earthquake (MCE) hazard levels. The results showed that the grout curtain performance is the main factor affecting the abutments' stability, while the materials' nonlinear behavior is the least affecting factor. Also, it was concluded that increasing the number of contraction joints could improve the seismic stability of the dam. A cap was observed on the number of joints, above which the safety factor did not change incredibly. [8].

Another study aimed to determine the critical seismic intensity at which cracks are expected to develop in a concrete arch dam. This intensity is referred to as crack initiation intensity. The crack initiation intensity measure implies that earthquakes with an intensity measure higher than this value are expected to induce cracks in the arch dam. This quantity is an indicator for the seismic evaluation of arch dams. Results were obtained by using three different endurance time excitation series 'kn,' 'kd,' and 'lc.' The aim of using three endurance time series was to compare their differences in the dynamic analysis of arch dams. Observations indicated the acceptable compatibility of these series of endurance time excitation. In order to investigate the accuracy of the results obtained by the endurance time method, the dynamic analysis of the arch dam subjected to ten ground motions scaled by the calculated crack initiation intensity measure was performed. It was shown that the proposed method could be conveniently applied to determining the crack initiation intensity [9].

One of the problems of modeling a dam system for thermal analysis is the application of ambient temperature in proportion to the execution time of each concreting layer. In some modeling, the effect of ambient temperature is considered as a fixed number, which is not the case in reality, where each concreting layer has its own environmental conditions. Therefore, each layer, depending on the execution time and environmental conditions simultaneously, should be entered into the problem and analyzed. In this research, the temperature and environmental conditions are considered carefully enough and for each concreting layer separately and enter into the problem. Another highlight of the research is showing the capability of the Abaqus software along with optimization in thermal analysis of rolled concrete dams, which is very efficient in terms of analysis time and parametric studies.

1.2 Conduction heat transfer

If the temperature of one part of the object is higher than the other, the heat will flow from the warmer part to the colder one. This phenomenon is called conduction. In this phenomenon, the transfer of thermal energy in the form of the flow of free electrons or the transfer of energy of the particles to adjacent particles occurs at a lower temperature. In this method, the heat transfer medium is stationary (solids), so the intensity of conduction heat transfer (the amount of heat transferred per unit time) is proportional to the temperature gradient in the object and the size of the heat transfer surface. Therefore, the intensity of conduction heat transfer based on Fourier's law is expressed as below:

$$q = -KA\frac{\partial T}{\partial x} \quad (1)$$

Equation (1) states that the thermal conductivity in an environment depends on the geometry, thickness, material, and temperature difference across the environment.

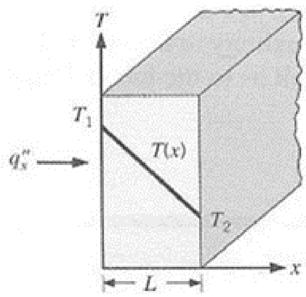

Fig. 1: One-dimensional conduction heat transfer [10]

Thus, Fourier's law expresses the mechanism of heat transfer by the conduction method.

Fourier's law is not based on analysis but on the human experience. Also, the negative sign in Fourier's law indicates a reduction in temperature transfer; in other words, heat cannot move from a cold point to a hot spot (second law of thermodynamics). Fourier's law is valid for all states (stable, unstable).

According to Eq. (1), if the temperature gradient is constant, the heat transfer will not depend on the thickness of the layer because the amount of heat transfer will be constant for each thickness.

1.3 Thermal diffusion coefficient

The thermal diffusion coefficient is a thermal property of an object that is defined as $\alpha = K/\rho c_p$. Therefore, the thermal diffusion coefficient indicates the velocity of heat diffusion inside the body; by increasing the numerical value of α, heat is diffused faster inside the body. On the other hand, according to the above relationship, by increasing the numerical value of the thermal conductivity (K) or decreasing the thermal capacity of the object (ρc_p), the thermal diffusion coefficient (α) will increase.

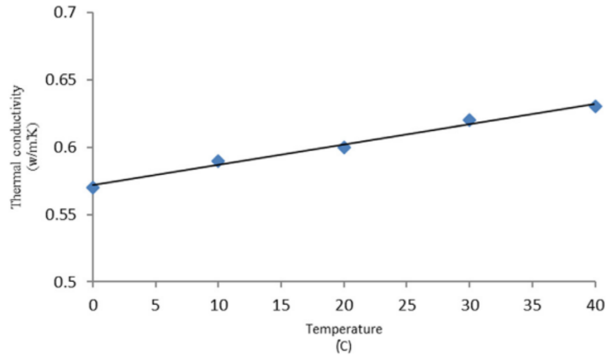

Fig. 2: Thermal conductivity of concrete [11]

1.4 Boundary and initial conditions

Solving the temperature equation requires having two boundary conditions for each spatial coordinate since it is second-order with respect to space and a primary condition as it is first-order with respect to time. Having boundary conditions in non-permanent problems such as the present study is very important because time is an influential factor in determining the answers to the problem. The boundary conditions used in this study are as in the following. [12].

A) Transient boundary condition: This state is obtained from the energy balance at the surface of the material in which there is heating or cooling by transfer heat transfer. Its general form in the process of heating and cooling is Eq. (2), where x is the known place where the heat exchange takes place:

$$-k\frac{\partial T}{\partial x} = h[T(x,t) - T_\infty] \quad (2)$$

where h is the convection coefficient in $\mathrm{W/m^2K}$ and T represents the temperature.

Heat transfer through convection is a complex phenomenon, and in numerical analyses, it is affected by many variables, including surface shape, surface roughness, viscosity, and fluid velocity that have a common border with the body. Nevertheless, the following formulas can be applied to heat transferred through convection with reasonable accuracy:

$$h = 5.7 + 3.8V \quad (3)$$
$$h = 2.8 + 3V \quad (4)$$

In these relationships, V is the velocity of the ambient air in m/s.

B) Common layer boundary condition: In the common layer of two objects A and B that are in contact with each other, both the temperature factor and the heat transfer rate must be the same; therefore, the boundary conditions at the common border of the two concreted layers will be as follows:

$$T_A(x.t) = T_S(x.t) \quad (5)$$
$$T_A(x.t) = T_S(x.t) \quad (6)$$

where x is the common layer location, t is time, and K is thermal conductivity.

2. Materials and Methods

For thermal analysis, the MATLAB software and the Perceptron neural network method, based on the multilayer method, have been used. This software has all the necessary capabilities for thermal analysis during the construction of the dam. Also, the execution time of each concreting layer has been done so that the temperature of each concreting layer changes under the influence of the applied conditions. When the responses in the software do not depend on the number of networks, one method of quality control of meshing is to use an error contour that indicates rapid changes in adjacent elements. Therefore, it can be said that the error command can identify areas of the model that have a high error in calculating the stress and where it is necessary to fine-tune the element to get a more accurate answer. As the elements shrink, the energy changes in the adjacent elements are sufficiently reduced to an acceptable value, resulting in an improved mesh surface [15].

2.1 Introduction of Perceptron Network

An artificial neural network is a software program or semiconductor chip that can act like the human brain. In fact, an artificial neural network is an idea for processing information inspired by the biological nervous system and processes like the brain. This system comprises a large number of processing elements called neurons that work together to solve a problem. The structure of artificial neural networks is introduced by the pattern of communication between nodes, the method of determining communication weights and functions, and the output layer is formed [14].

In multilayer neural networks, there is an input layer that receives information, there are several hidden layers that receive information from the previous layers, and finally, there is an output layer to which the computation results go, and the output is the final output of the network [3].

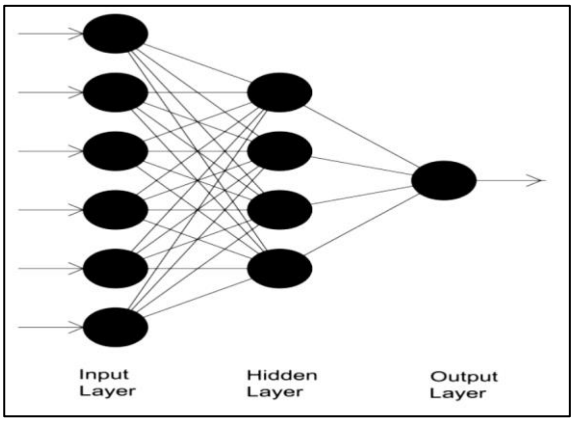

Fig. 3: An example of an artificial MLP network with a hidden layer [3]

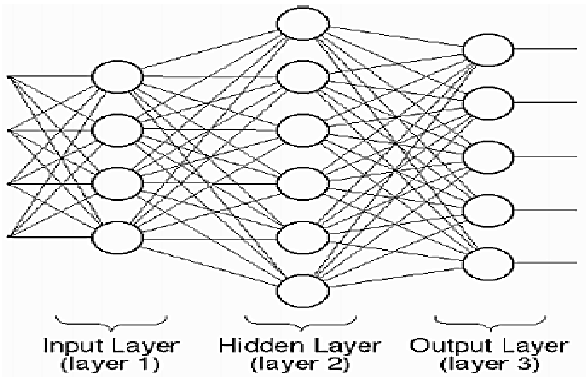

Fig. 4: An example of a three-layer network

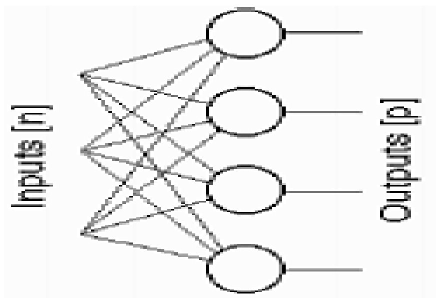

Fig. 5: An example of a single layer network

The Perceptron algorithm is an iterative algorithm in which first the weight vectors are quantified, and then at each step, the algorithm changes the weight and bias values according to the points that are not categorized correctly so that these points are categorized correctly. If the given points are not linearly separable, the Perceptron algorithm does not end, but if the linear points are separable, the algorithm ends in a finite number of steps. [16]

2.2 Introducing the specifications of the Case study

The selected dam for the present study is the Zhaveh concrete dam. This dam was constructed in Kurdistan province and on the Zhaveh river. This dam is the largest rolled concrete dam built in Iran and has a record of concreting at 121,000 cubic meters per month. Moreover, the transmission system is one of the largest water transmission systems in the country due to its capacity and dynamic pumping head of about 900 meters. Figure 6 shows a view of the Zhaveh Dam.

Fig. 6: View of Zhaveh Dam [17]

The technical specifications of Zhaveh Dam are presented in Table 1.

Table 1: Technical specifications of the Zhaveh Dam [17]

Technical specifications of Dam	Value
Height of the dam	86.5 (m)
Length of the crest	300 (m)
Sea level	2000 (m)
Number of pumping stations	6
Water volume	123 (m3/s)
The maximum capacity of the dam	8 (m3/s)
Piping diameter	2000 (mm)
Piping length	288.32 (km)
Downstream slope	1: 1

In this analysis, the initial temperature of concrete is 15, and the average annual temperature is 13.8 °C. Also, the time interval between implementing two consecutive layers of 3 days and nights is considered. To analyze the model, the concrete and the dam's foundation materials are assumed to have homogeneous, linear, and isotropic behavior. Considering that the primary purpose of this research is to conduct the thermal analysis of a concrete dam, the dam and the foundation system are considered integrated. In addition, the dam's foundation is assumed to be rigid, and the effect of temperature changes on the concrete of the body has been investigated. Table 2 shows the mechanical properties of concrete materials in the section of the dam.

Table 2: Mechanical properties of concrete

Density	E	F'_c	Poisson
Kg/m^2	GPa	MPa	-
2450	2.96	25	0.3

Table 3 shows the thermal characteristics of concrete in the section of the dam.

Table 3: Thermal properties of concrete

Thermal conductivity coefficient	Specific Heat	Convection coefficient
W/m.C'	J/Kj.C'	J/m2.Day.C'
2.96	970	1500000

Figure 7 shows the cross-section of the Zhaveh Dam in the Kurdistan Province.

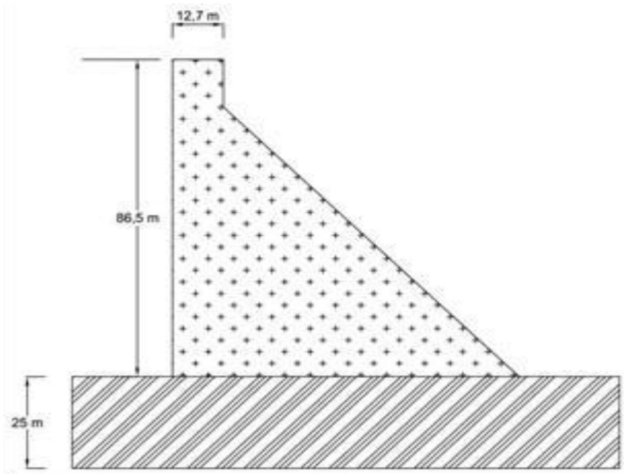

Fig. 7: Cross-section of Zhaveh rolled concrete dam [13]

Moreover, the air temperature at the construction site of Zhaveh Dam is according to the reports described in Fig. 8.

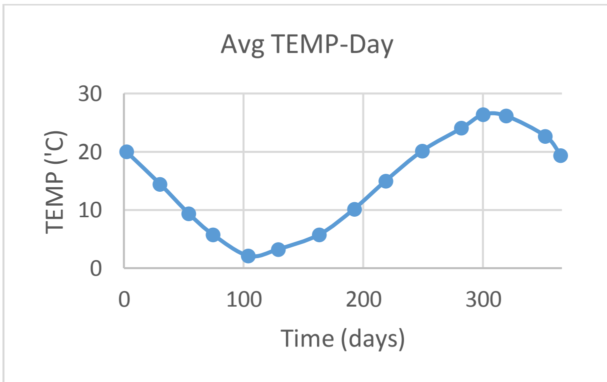

Fig. 8: Annual temperature changes at the site of Zhaveh Dam [18]

The diagram of the adiabatic temperature rise of the dam's rolled concrete mix with 25% pozzolan is as shown in Fig. 9.

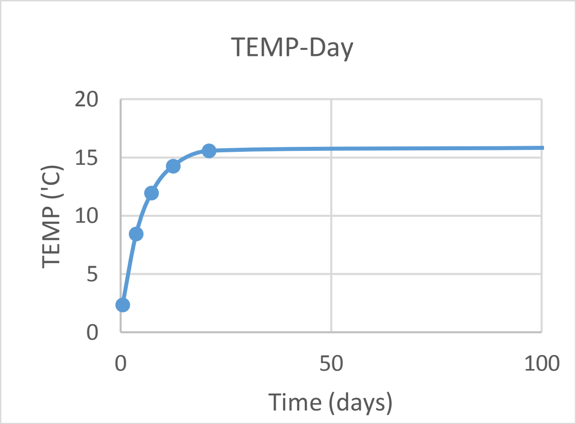

Fig. 9: Adiabatic temperature of concrete in Zhaveh Dam [18]

2.3 Validation

For validation, the thermal analysis results in this paper are compared with the values of thermal meters provided by the Jyane Construction Company in 2006 for the level of 4 meters from Zhaveh Dam. For this purpose, first, for the temperature changes over a year at the dam site, the results presented at the construction site are compared with the results of this study as shown in Figs. 10 and 11, for a level of 4 meters at 90 and 150 days after start. [13]

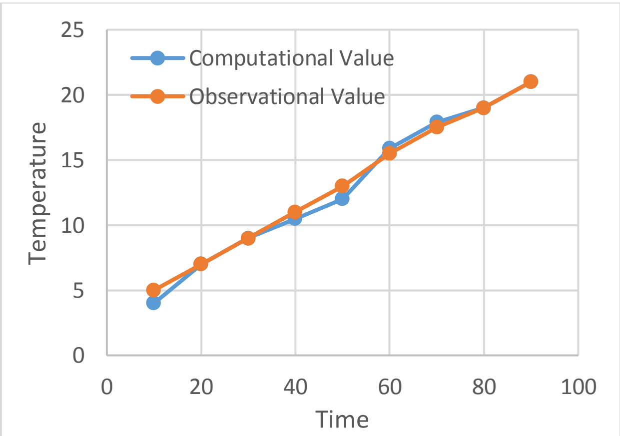

Fig. 10: The temperature of the points located at the level of 4 meters at the end of December

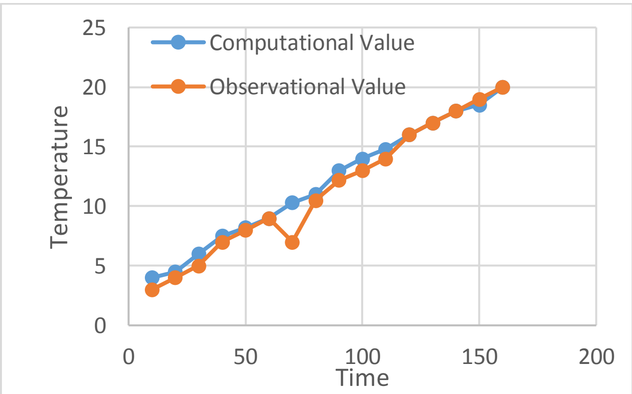

Fig. 11: Temperature of points located at the level of 4 meters at the end of February

3. Dam modeling in Abaqus

For the structural analysis in this research, the powerful Abaqus software has been used, so the steps of thermal analysis and analysis in this software are as follows:

3.1 Loading

In the loading module, the effect of gravity on the concrete mass is introduced to take into account the weight of the layers and the boundary conditions of the dam section.

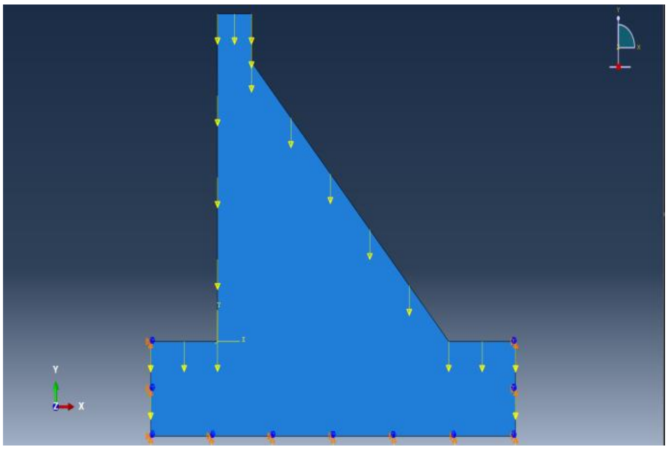

Fig. 12: Gravity force of the dam

The application of thermal changes is as follows: For the structure of 50-cm layers, a hypothetical layer is considered. Each layer takes 72 hours (259200 seconds) of the analysis time, at which time the hypothetical concrete layer is generating hydration heat at the same time. The previous layer and layers of heat generated diffusion, and also at the air-concrete boundary, heat transfer occurs based on the amount of air heat transfer and the temperature difference between air and concrete. To simplify the solution and reduce its time, instead of air modeling, we used the definition of air heat transfer rate and average air temperature during analysis (construction) and assigned it to the common boundary between concrete and air.

3.2 Boundary conditions in finite elements

The finite element method and software based on this numerical solution method should be considered engineering tools that appropriate skills and attention of users can lead to valuable results and avoid spending a lot of economic costs. Therefore, the boundary conditions of the dam foundation are also defined by the constraint (two-dimensional).

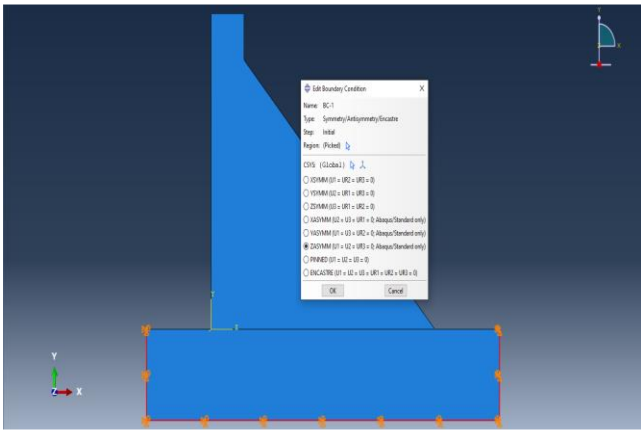

Fig. 14: Boundary conditions of the dam

3.3 Principles of meshing structures

Among methods used to evaluate the appropriateness of the dimensions of the elements is to examine the German results in the model. The presence of large discontinuities and jumps in the results in one element confirms the low accuracy of the analysis. Of course, finite element software such as Abaqus can identify areas with a high analysis error, called error estimation. In meshing and producing the required elements for all models of structures, meshing has been done carefully, and the quality of the elements has been confirmed.

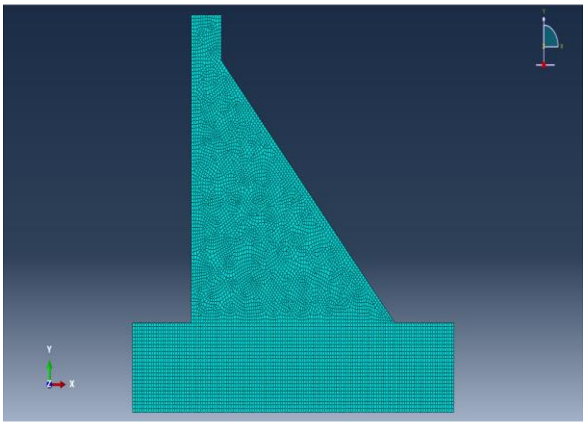

Fig. 15: The meshing of the concrete dam structure

3.3 Problem-solving method

In the Step module, the type of analysis or analyses that can be performed by Abaqus software is determined in the form of a step definition. Each analysis is done in the form of a step. In this research, Coupled Temp-Displacement analysis is used to apply the temperature changes of concrete, and Static-General analysis is used to apply gravity and hydrostatic forces after the construction period. Analysis in both cases is in the linear range.

Analysis time at the time of dam construction is 519 days, equivalent to 44841600 seconds.

The time of static analysis after the construction period is considered to be 2 seconds, which is the time of applying the hydrostatic load.

In general, the problem is analyzed 12 times. Each analysis is based on the start of the project in different months of the year to achieve the optimal construction time based on the maximum temperature in the dam's concrete and the stresses created by it by collecting the information and using the Perceptron network algorithm.

4. Result and Discussion

4.1 Analysis of the results of Abaqus

Figure 16 shows the concrete heat contour up to the 30th layer. The maximum temperature of concrete is 21.07 °C.

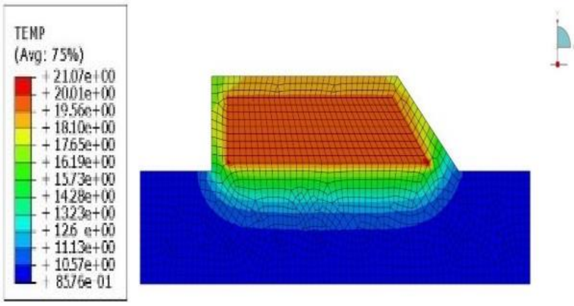

Fig.16: The maximum temperature generated at the level of 15 meters (30 layers) - Project started in October

Figure 17 shows the concrete heat contour up to the 60th layer. The maximum temperature of concrete is 19.86 °C.

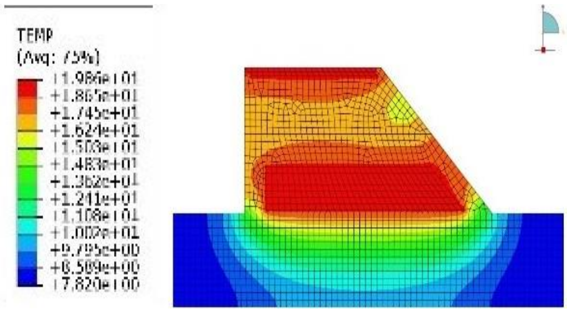

Fig.17: Maximum temperature generated at the level of 30 meters (60 layers) - Project started in October

Figure 18 shows the concrete heat contour up to the 120th layer. The maximum temperature of concrete is 28.60 °C.

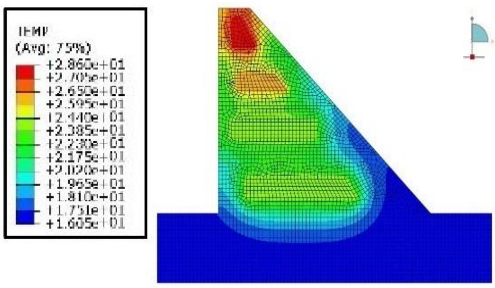

Fig.18: The maximum temperature generated at the level of 60 meters (120 layers) - Project started in October

Figure 19 shows the concrete heat contour up to the 173rd layer with the start of the project in October (end of concreting). The maximum temperature of concrete is 22.51 °C.

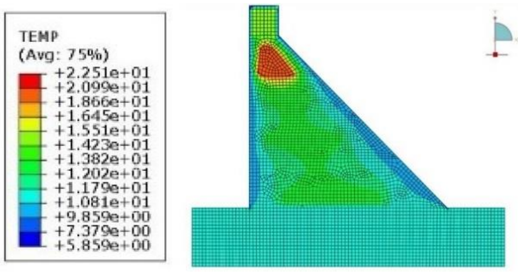

Fig. 19: The maximum temperature generated at the level of 86.5 meters (173 layers) - Project started in October

Figure 20 shows the maximum temperature changes of concrete with the start of the project in October, November, and December. According to the obtained diagram, the maximum temperature produced in concrete with the start of the project in October, November, and December is about 30 °C. The minimum temperature produced in concrete is about 10 °C with the start of the project in December. The lowest maximum temperature is related to the start of the project in December.

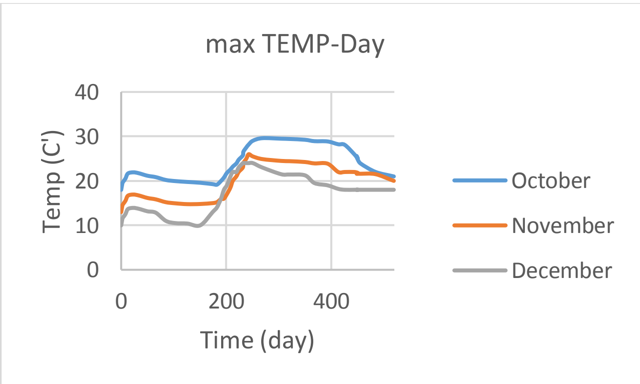

Fig. 20: Diagram of changes in maximum concrete temperature with the start of the project in October, November, and December

Figure 21 shows the maximum temperature changes of concrete with the start of the project in January, February, and March. According to the obtained diagram, the maximum temperature produced in concrete with the start of the project in January, February and March is 17 °C. The lowest temperature produced in concrete is about 2 °C and is related to the start of the project in January. The lowest maximum temperature is related to the start of the project in January.

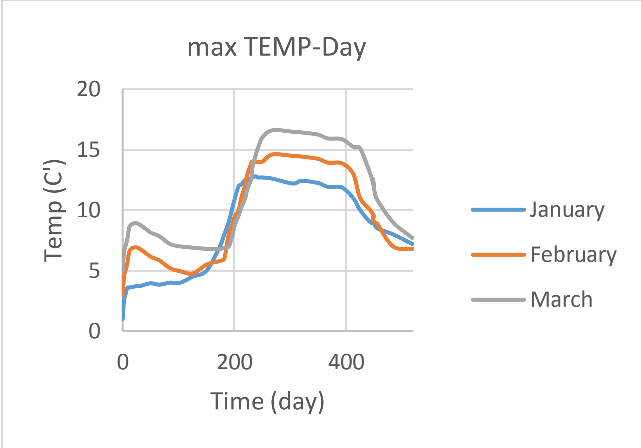

Fig. 21: Diagram of changes in maximum concrete temperature with the start of the project in January, February, and March

Figure 22 shows the maximum temperature changes of concrete with the start of the project in April, May, and June. According to the obtained diagram, the maximum temperature produced in concrete with the start of the project in January, February and March is 28 °C and is related to the start of the project in June. The minimum temperature produced in concrete is about 10 °C is related to the start of the project in April. The lowest maximum temperature is related to the start of the project in April.

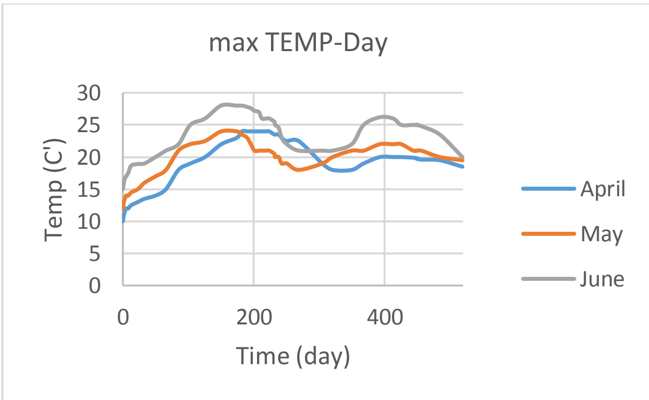

Fig. 22: Diagram of changes in maximum concrete temperature with the start of the project in April, May, and June

Figure 23 shows the maximum temperature changes of concrete with the start of the project in July, August, and September. According to the obtained diagram, the maximum temperature produced in concrete with the start of the project in January, February, and March is 32 °C and is related to the start of the project in July. The minimum temperature produced in concrete is about 16 °C and is related to the start of the project in September. The lowest maximum temperature is related to the start of the project in September.

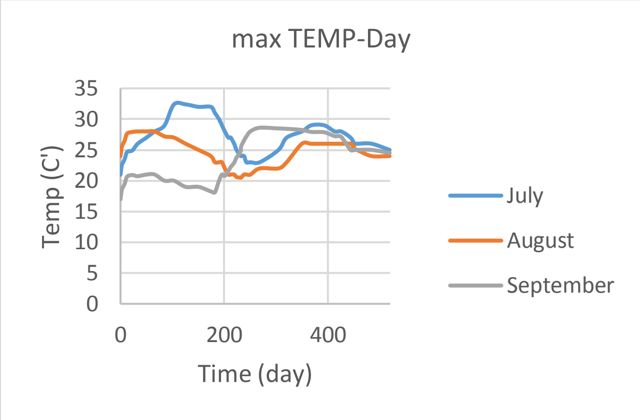

Fig. 23: Diagram of changes in the maximum temperature of concrete with the start of the project in July, August, and September

Figure 24 shows a comparison chart of the maximum concrete temperature with the start of the project in different months of the year. According to this diagram, the maximum temperature with the start of the project in different months of the year is 32 ℃ which is related to the start of the project in July. Moreover, the lowest maximum temperature produced is 12.7 ℃ which is related to the start of the project in January.

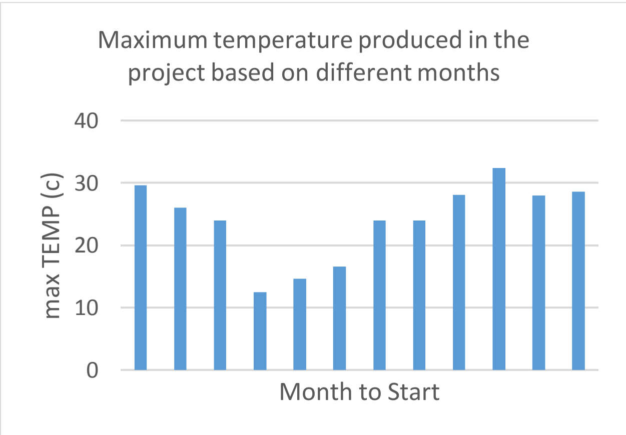

Fig. 24: Diagram of the maximum temperature of concrete with the start of the project in different months of the year

Figure 25 shows a comparison chart of the maximum tensile stress of concrete with the start of the project in different months of the year. According to this diagram, the maximum tensile stress with the start of the project in different months of the year is 4.12 MPa and is related to the start of the project in July, and the minimum tensile stress of concrete is 1.028 MPa and is related to the start of the project in January.

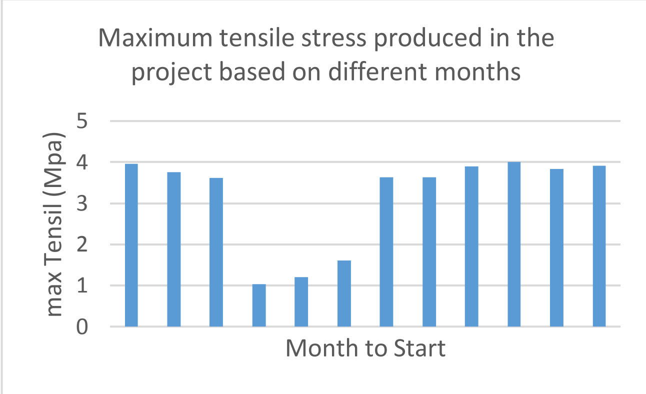

Fig. 25: Diagram of the maximum tensile stress of concrete with the start of the project in different months of the year

4.2 Results of modeling in Perceptron network

Day input and temperature output are given every 12 months to form 12 multilayer Perceptron neural networks with different Levenberg-Marquardt learning algorithms. Considering the number of different layers, it was found that in each network, 5 layers with the number of neurons 4, 4, 8, 8, and 16 are suitable from the first layer to the fifth layer, respectively. 100% of the data is selected for training, and 0% of the data is selected for testing. After training the network, the results were obtained for the rest of the year (12-365) as the start day of the project with a length of 519 days. By comparing the results, it was found that the lowest maximum concrete temperature will be obtained if the project starts on January 11.

Figure 26 shows the diagram of changes in the maximum temperature of concrete with the start of the project on different days during the year (365 days), which is obtained by the MATLAB software and Perceptron algorithm by reconstruction of the data obtained from Abaqus analysis results to start the project on the first day of each month. The result of this data reconstruction is creating information to start the project on any day of 365 days of the year.

By starting the project on the 101st day (equivalent to January 11), we see the lowest maximum temperature produced in concrete during the 519-day project of dam construction.

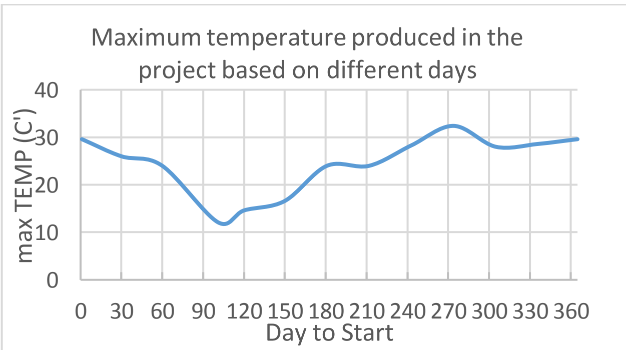

Fig. 26: Diagram of maximum temperature changes of concrete with the stars of the project on different days during the year

Figure 27 shows the maximum temperature changes of concrete with the start of the project on January 1 and 11. The diagram of concrete temperature changes for the first day of January was obtained from Abaqus results, and the diagram of concrete temperature changes for the start of the project on the 11th day was obtained by the MATLAB software with the Perceptron algorithm.

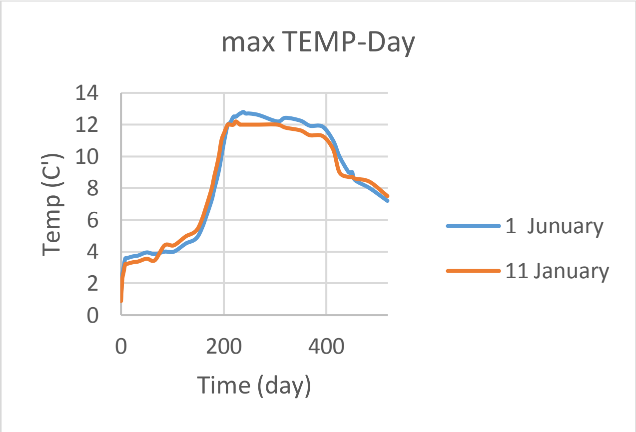

Fig. 27: Diagram of comparing the maximum temperature changes of concrete with the start of the project on January 1 and 11.

According to the obtained diagram, the maximum temperature produced in concrete with the start of the project on January 1 is 12.7 °C. Nonetheless, if the project starts on January 11, the maximum temperature of concrete produced is 12.1 °C.

5. Conclusion

One of the problems of modeling the dam system for thermal analysis is the application of ambient temperature in proportion to the execution time of each concreting layer. Summary of the results obtained are as follows:

1- By thermal analysis of the dam in Abaqus, the thermal analysis results for the rolled concrete dam for 12 months of the year can be obtained by starting the project on the first day of each month. According to this analysis, the start of the project in January resulted in the lowest maximum concrete temperature during the dam's construction (based on months).

2- Using Perceptron and a machine learning algorithm based on Abaqus input and output data obtained from 12 thermal analyses of the dam to start from the beginning of each month, new data from the thermal analysis can be obtained for all days of the year to determine the best day of the year to start the project. In other words, using thermal analysis of the dam by Abaqus and its optimization by the Perceptron algorithm in the present study, with the start of the project on January 11, the lowest maximum concrete temperature is obtained during the construction of the dam (based on days).

3- In this study, according to the process of decreasing the temperature of the central part of the dam in the analysis of 520 days after completion and during the operation period, it is predicted that the time to reach the final equilibrium temperature of the dam will take about a decade.

4- At different application times, tensile stresses in the bed and on the outer surface occur due to external and internal constraints, respectively (entrapment due to changes in ambient temperature and non-uniform temperature production). Because the thermal conductivity of concrete is low, the thermal slope due to the difference between the internal temperature of the concrete and the environment is limited to a distance of 3 to 4 meters from the concrete surface.

5- Considering the weight of the layers in stress analysis causes the tensile strain values to be significantly reduced, and especially this reduction is more pronounced in the bed. Given that the weight of the layers actually affects this effect, it must be considered in the analysis of the strains created.

6- Regarding the limitations of the research, it can be mentioned that the mentioned results, although based only on the analysis of a dam, can be somewhat different for different conditions and years but are reliable in terms of overall and practical validity.

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