Thermal Assessment of Karun-1 Dam

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Abstract: In this study, the simulation of the thermal behavior of an arch dam which is subjected to the environmental thermal action during service, the method of solution adopted as well as the evaluation of the different parameters will be described in detail. The case study is a double curvature concrete arch dam (Karun-1 dam) with 200 m height in the Southwest of Iran which is modeled by the powerful scientific ABAQUS software. The ABAQUS program has the ability to transfer heat within the body of the dam with high accuracy, the main challenge of previous researches in the field of thermal analysis of arch dams. In addition to thermal loads, in this study, the effects of hydrostatic pressure and weight of the dam and reservoir-dam-foundation interaction also have been considered and it became distinct that the thermal effects on dam displacements, stresses and strains are significant and would not be neglected.

Key words: Thermal analysis, arch dam, finite elements method, tensile, compressive, stress, ABAQUS

INTRODUCTION

Iran is a semi-dry country in the Middle East and has an average annual rainfall about 250 mm, which is less than the average Asia rainfall. Climatic diversity, Inharmonic place and time distribution of surface flows are the main features of a large part of Iran; therefore, storage of water is a big challenge in this country. In the past decades, dam construction in Iran is one of the most usage ways to store water. For example, Khuzestan province in Southwest of Iran has several arch dams.

Dams are the large buildings built by human civilization and because of their complexity and involved physical, geo mechanical, hydrological, structural design and construction parameters need to heavy investment. Among these, concrete arch dams are complicated three dimensional structures and have a sophisticated design and construction methods and in many cases are as the most economical option. Therefore, arch dam structure must be controlled against all possible risks and forces.

Simultaneously with improvement in design and construction technology, it is necessary to use proper scientific methods to reduce cost and time of dam projects. Finite element method as a powerful numerical method is one of most applicable scientific methods that can be used to solve many problems in dam engineering and in various modes of analysis such as stable, transient, linear and nonlinear cases.

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Arch dams in comparison to gravity dams have the wider surface and less thickness, so, temperature differences between upstream and downstream faces of these dams can cause larger stress and strains in relative to their corresponding values in gravity dams.

Khuzestan province in Iran has a warm summer. Sometimes the reported temperature value in some portion of this province is higher than 122°F which is a relatively high temperature, so it would be rational to investigate thermal effects in large structures such as arch dam in this area. One of these arch dams is Karun-1 that is the case study of this research. In recent years, the safety control of this dam is highlighted due to the fact that the electrical energy generation of the dam has been increased thorough the development of the second phase of its power plant. So, for case study, this dam was selected.

When Karun-1 dam reservoir is full, downstream face of dam is exposed completely to a sunlight radiation, at the same time upstream face is in the vicinity of water. So we have a big temperature gradient across the thickness of the dam and eventually lead to creation of mechanical-thermal forces and moments. The dam’s temperature field during construction is related to the process of concreting, water impoundment, air temperature, solar radiation, etc. It is a variation temperature field. Concrete expands when temperature rises and shrinks when temperature falls, the magnitude of expansion or shrinkage is proportional to coefficients of thermal expansion, magnitude of temperature rising or falling and the size of dam block. When dam block is restricted by outer or interior restriction, the volume deformation cannot occur freely and thermal creep stress will appear (Stigerard et al., 2001; Yuan and Wang, 2002; Faris et al., 2006; Li et al., 2009; Garas et al., 2009). If thermal creep stress is beyond the allowable thermal creep stress of corresponding age of concrete, crack will occur. So, it is necessary to use 3-D FEM to simulate the whole process of the temperature field and thermal creep stress of an arch dam considering all the changing factors during construction.

In the field of thermal analysis of concrete dams especially arch dams, limited research has been done so far that some of them will be mentioned in continue.

Malla and Wieland (1999) investigated a created horizontal crack in a concrete gravity dam after 25 years from starting operation time. They considered the effect of temperature in their study and used ADINA finite element program. Their results showed that daily temperature changes (cooling and warming) could not be the reason of crack creation. Luna and Wu (2000) developed a 3D finite elements program to simulate the construction process of a RCC gravity dam in China. They considered in their study how the temperature changes can alter the elastic modulus and creep behavior of concrete. They concluded that it is feasible to construct the dam in low temperature seasons without any special temperature control measurements. Amin et al. (2009) conducted an experimental study in order to simulate the generated stress field due to temperature variations in mass concrete. They also provided a numerical simulation using DIANA finite elements method to verify and extend the experimental interpretations. Manafpour et al. (2009) implemented a 3D finite element model of a concrete gravity arch dam and examined the effects of earthquake and thermal loading, simultaneously. Earthquake excitations are applied to dam in three orthogonal directions and thermal loads are calculated based on minimum and maximum mean daily ambient air temperatures at the site. They concluded that the thermal load was important and can cause crack initiation in the dam.

Nisar et al. (2006) studied 2D and 3D models of a concrete dam with considering the effects of thermal load created from Hydration (in a 10 years interval). This work has been done by the finite element ABAQUS software. Sheibani and Ghasemian (2006) incorporated the thermal stress field in Karaj arch dam in Iran. They contributed in their study the effect
of solar radiations as well as other resources of heat generation in dam like air and reservoir temperature changes. They concluded that two dimensional thermal analysis of an arch dam can not yield accurate results and 3D numerical simulation is needed.

Examining the study, it is revealed for the researchers that heat transfer formulation is an important challenge in thermal analysis of arch dams. To overcome this problem, in our research, we use ABAQUS software. This program has several advantages which one of them is the ability to model heat transferring across the thickness of the dam with high accuracy. Furthermore the program can simulate dam-foundation interaction well.

In this study, firstly, body and the abutments of karun-1 dam have been modeled with good accuracy using the As-built drawings of the dam in ABAQUS program and usage of preprocessor programs including CATIA and MATLAB. After that, two type of analysis have been done: First analysis done without considering thermal effects (without-temp) and second analysis considered the thermal loading (with-temp). It is important to note that in two analysis cases, dam weight and hydrostatic pressure of reservoir is implemented. Then, 2 groups of results are compared with each other.

MATERIALS AND METHODS

In a general simple way, the range or amplitudes of concrete temperatures arising from exposure to air and water can be determined by a simplified method or the finite-element method. In the simplified method, assumed external sinusoidal temperature variations are applied to the edges of a theoretical flat slab, whereas in FEM they are applied to the faces of a finite-element model of the dam using a conductive boundary condition.

The simplified method has been described fully by USBR (Townsend, 1965) and is based on computation of heat flow through a flat slab of uniform thickness exposed to sinusoidal temperature variations on both faces. The method has been simplified by reducing the heat flow computation into a curve showing the ratio of the variation of the mean temperature of the slab to the variation of the external temperature as a function of an effective slab thickness. The simplified method can be used in the trail load method as well as the FEM.

Temperature Field

For mass concrete, it is not enough to dissipate heat by surrounding air and cooling water should be used to decrease the temperature of mass concrete. Bofang (1991) advanced the equivalent equation of heat conduction in mass concrete considering the effect of pipe cooling:

$$\frac{\partial T}{\partial \tau} = \alpha \left( \frac{\partial^2 T}{\partial \tau^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) + (T_e - T_0) \frac{\partial \phi}{\partial \tau} + \theta_0 \frac{\partial \nu}{\partial \tau}$$

(1)

Where:

- $T$ = Temperature of concrete
- $T_0$ = Initial temperature of concrete
- $T_c$ = Inlet cooling water temperature
- $\theta_0$ = Final adiabatic temperature rise of concrete
- $\phi$ = Function related to length and space of cooling pipe and adiabatic temperature rise enameate speed of concrete
- $\nu$ = Remaining coefficient of hydration heat
- $\alpha$ = Thermal diffusivity coefficient
The method considers the cooling pipe as a negative source of heat and formulas are given to take into account the effect of pipe cooling in average. By this method, the problems such as over many elements and nodes, large capacity of memory, long time of computation are avoided and it is convenient to the whole temperature field simulation process of mass concrete lasting many years.

**Thermal Creep Stress**

Lingfei and Yang (2008) presented basic calculation equations (relations 2–6) of thermal creep stress as follows:

\[
[K].[\Delta \delta] = [\Delta P_L] + [\Delta P_C] + [\Delta P_T] + [\Delta P_V] \quad (2)
\]

Where:

- \( K \) = Stiffness matrix
- \( [\Delta P_L] \) = Node load increment caused by exterior load
- \( [\Delta P_C] \) = Node load increment caused by creep of concrete
- \( [\Delta P_T] \) = Node load increment caused by temperature difference
- \( [\Delta P_V] \) = Node load increment caused by autogenous volume deformation

Thermal creep stress increment of each time iterative is:

\[
[\Delta \sigma_x] = [\Delta \delta](\{\Delta \epsilon_x\} - \{\Delta \eta_x\} - \{\Delta \epsilon_C\} - \{\Delta \epsilon_T\} - \{\Delta \epsilon_V\}) \quad (3)
\]

\[
[\Delta \delta] = [\mathcal{E}_d][\mathcal{Q}]^{-1}, [\mathcal{Q}] = \begin{bmatrix}
1 & -\nu & 0 \\
-\nu & 1 & 0 \\
0 & 0 & 2(1 + \nu)
\end{bmatrix} \quad (4)
\]

Where:

- \( [\Delta \epsilon_x] \) = Element's strain increment caused by node displacement
- \( [\Delta \eta_x] \) = Element’s strain increment caused by creep of concrete
- \( [\Delta \epsilon_C] \) = Element’s strain increment caused by temperature difference
- \( [\Delta \epsilon_V] \) = Element’s strain increment caused by autogenous volume deformation
- \( \mathcal{E}_d \) = Equivalent elasticity module \( \nu \) is poisson's ratio

The final thermal creep stress equals to the sum of all the thermal creep stress increment, that is:

\[
[\sigma_x] = [\Delta \sigma_x] + [\Delta \sigma_y] + [\Delta \sigma_z] + ... + [\Delta \sigma_n] = \sum [\Delta \sigma_x] \quad (5)
\]

**Thermal Creep Stress Control Standard**

Design Specification for Concrete Arch Dam (SL282-2003, in Chinese) demands that horizontal tensile stress should be controlled by equation:

\[
\sigma \leq \frac{\varepsilon_v E_c}{K_f} \quad (6)
\]

Where:

- \( \sigma \) = Thermal creep stress caused by temperature difference
- \( \varepsilon_v \) = Ultimate tensile strain of concrete
Table 1: Allowable horizontal tensile stress/Mpa

<table>
<thead>
<tr>
<th>Concrete type</th>
<th>Allowable value</th>
</tr>
</thead>
<tbody>
<tr>
<td>R400</td>
<td>1.80</td>
</tr>
<tr>
<td>R350</td>
<td>1.60</td>
</tr>
</tbody>
</table>

$E_c = \text{Elasticity module of concrete}$

$K_r = \text{Safety coefficient and ranges from 1.3-1.8 (K_r equals 1.8 in this study)}$

The maximum thermal creep stress appears at the end of second-stage and the corresponding age of concrete is 180 days. So, the allowable horizontal tensile stress adopts the concrete’s allowable tensile stress at the age of 180 days. The results shown in Table 1.

Where ever, the tensile stress reaches the calculated maximum value, which is the main factor of causing thermal cracking, it can be assumed that is cracked.

**Solar Radiation on the Dam Faces**

In absence of actual measurements of the local solar radiation, the data that is commonly used pertain to the monthly average of the daily global solar radiation on a horizontal surface ($H_o$). The present model obtains the incident solar radiation on the dam faces.

Using the monthly average $H_o$, the method proposed by Liu and Jordan (1963, 1967) permits the calculation of the daily diffused radiation on the surfaces $H_d$ by obtaining the direct component of the radiation, $H_s$, as the difference between the two. The relation between $H_s$ and $H_d$ it is expressed by

$$H_d = H_o(1.39 - 4.027K_r + 5.531K_r^2 - 3.108K_r^3)$$ (7)

where, $K_r$ is the index of the average monthly cloudiness, defined by the ratio between $H_o$ and the monthly average of the extraterrestrial solar radiation ($H_e$).

The extraterrestrial solar radiation can be evaluated through the expression

$$K_r = \frac{H_o\pi}{24r^2I_{SC}(\cos \delta \cos \phi \sin (h_r) + h_r \sin \delta \cos \phi)}$$ (8)

where, $r^2$ is the correction factor of the solar constant for every day of the year

$$r^2 = 1 + 0.003\cos\left(\frac{360Z}{365}\right), \quad 1 \leq Z \leq 365$$ (9)

Where:

$I_{SC} = \text{Solar constant}$

$\text{ISC} = 4870.8 \text{ KJ/hm}^2$

$\delta = \text{Latitude of the location}$

$\phi = \text{Solar declination}$

$h_r = \text{Absolute value of the hourly angle corresponding to sunset, expressed in radians.}$

The declination can be obtained from tables or approximate formulas that express the declination as a function of the day of the year for example Duffie and Beckman (1974).

Nevertheless, in order to calculate the declination, a representative day is normally obtained for every month. This representative day is usually taken to be that when the extraterrestrial radiation is closest to the value of the average daily extraterrestrial radiation during the given month. In Table 2, after Coronas et al. (1982), the representative day for every month hand the corresponding value of the solar declination are presented.
Table 2: Middle days and their solar declination

<table>
<thead>
<tr>
<th>Month</th>
<th>Middle day</th>
<th>Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>17</td>
<td>-20.7</td>
</tr>
<tr>
<td>February</td>
<td>15</td>
<td>-12.6</td>
</tr>
<tr>
<td>March</td>
<td>16</td>
<td>-1.7</td>
</tr>
<tr>
<td>April</td>
<td>15</td>
<td>9.8</td>
</tr>
<tr>
<td>May</td>
<td>15</td>
<td>18.9</td>
</tr>
<tr>
<td>June</td>
<td>17</td>
<td>23.0</td>
</tr>
<tr>
<td>July</td>
<td>17</td>
<td>21.2</td>
</tr>
<tr>
<td>August</td>
<td>17</td>
<td>13.4</td>
</tr>
<tr>
<td>September</td>
<td>16</td>
<td>2.6</td>
</tr>
<tr>
<td>October</td>
<td>16</td>
<td>-8.9</td>
</tr>
<tr>
<td>November</td>
<td>15</td>
<td>-18.5</td>
</tr>
<tr>
<td>December</td>
<td>11</td>
<td>-23.0</td>
</tr>
</tbody>
</table>

The hourly angle \( h_s \) corresponding to sunset is obtained from

\[
\cos(h_s) = -\tan \alpha \tan \delta
\]  

(10)

where, \( h_s \) is the hourly angle that corresponds to sunrise.

Knowing the hourly angles of sunrise and sunset, the duration of the solar day (TSV) can be determined. This duration is the time between two consecutive passes of the sun over the longitude of the location. The relation between TSV (in hours) and the hourly angle (in degrees) is given by:

\[
h = 15(TSV - 12)
\]  

(11)

and consequently, the beginning (TSV\(_b\)) and the end (TSV\(_d\)) of the solar day, as well as the duration (TSV) are defined through the relations:

\[
TSV_b = 12 - \frac{1}{15} \cos^{-1}(-\tan \alpha \tan \delta)
\]  

(12)

\[
TSV_s = 12 - \frac{1}{15} \cos^{-1}(-\tan \alpha \tan \delta)
\]  

(13)

\[
TSV = 12 - \frac{2}{15} \cos^{-1}(-\tan \alpha \tan \delta)
\]  

(14)

These relations depend only on the location of the dam (\( \delta \)) and the day of the year (Z); therefore, for a given dam, the interval of solar radiation at its location can be determined. Outside this interval, the incident solar radiation is taken to be zero.

The direct component of the radiation is obtained as mentioned previously:

\[
H_s = H_t - H_d
\]  

(15)

Once the direct and diffuse components of the monthly average of the daily global radiation at the location (horizontal plane) have been determined, we get the hourly radiation at different times during the interval that corresponds to sunrise and sunset at the location of the dam.

**Coefficients of Heat Transfer**

The coefficient of the heat transfer by radiation, \( h_r \), is evaluated at every instant as a function of the temperature of the environment and the surfaces and of the Stefan-Boltzmann
Table 3: Geometrical specifications of Karun-1 dam

<table>
<thead>
<tr>
<th>Dam type</th>
<th>Double curvature arch dam (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of crest</td>
<td>3702.0</td>
</tr>
<tr>
<td>Height from foundation</td>
<td>200.0</td>
</tr>
<tr>
<td>Thickness at base</td>
<td>33.5</td>
</tr>
<tr>
<td>Thickness at crest</td>
<td>6.0</td>
</tr>
<tr>
<td>Normal water level</td>
<td>180.0</td>
</tr>
</tbody>
</table>

Fig. 1: Upstream view of Karun-1 dam

constant. Therefore, its implementation can be achieved through parameters that already have been analyzed.

The coefficient of heat transfer by convection, $h_c$, is treated as input data for the analysis, with the option that it can vary throughout the year. This coefficient, which depends on many factors, is a function primarily of the wind velocity and can be related to it empirically as proposed by several researchers. In this work, the formula of Keilbeck (1978) is utilized, as in other related works (Agullo et al., 1996).

$$h_c = 3.85v + 4.67$$ (16)

Where, $v$ is the velocity of the wind expressed in m sec$^{-1}$ and $h_c$ in W m$^{-2}$ K$^{-1}$. Consequently, the determination of the coefficient of heat transfer by convection proposed in this model is realized through the wind velocity at the dam site, which permits the analysis of its influence on the thermal behavior of the dam.

Other aspects of the numerical analysis can be found by Agullo (1991).

Geometrical Specifications

To verify the proposed method, a real case study used to have a real simulated temperature effect model of arch dam. The proposed numerical simulation was done thorough several months in 2009. It is clear that creating the geometry and analyzing a double curvature arch dam is a difficult work but on the other hand, the results could be precise and similar to real condition. Also, by evaluation of dam modeling and by predicting the behavior of the structure it is possible to find the weak point in accordance with loading conditions and we can do the best to detect it and repair or remove the defect.

Based on the above mentioned viewpoint, the necessary information of Karun-1 dam for modeling was derived from As-built drawings. Karun-1 is a double curvature arch dam with 200 m height. Additional dam characteristics are shown in Table 3.

In this dam, internal and external arch radiuses and also internal and external arch angles in various levels are different. Also, internal and external arches of the dam are not concentric and the dam is not symmetrical to the axis that crosses from the centers of arches.

So, this dam has almost all intricacies that a dam could have (Fig. 1-3).
Fig. 2: Downstream view of Karun-1 dam

Fig. 3: Plan view of Karun-1 dam

It is important to note that, for accurate modeling of the dam body, three scientific programs were used: ABAQUS, CATIA and MATLAB.

Karun-1 Dam in Khuzestan province, is located in a distance of 55 km at North of Masjed Suleiman, on the Karun river.

Material Specifications
Materials properties of Dam and its support are shown in Table 4.
Finite Elements Library

Dam

To have an analogy between the geometry of dam and model, 20 nodal, 3D elements (C3D20RT) with 2 degree curvature are used in ABAQUS program and shown in Fig. 4. The dam body includes 2670 elements totally.

Abutments

For support geometry modeling, Elements of three-dimensional 10 nodal (C3D10MT) with 2 degree curvature are used in ABAQUS (Fig. 5). Because, the number of support elements is too much, so for reduction of calculation time and memory consumption this type of element is used. A mesh with 12165 elements is used for support model.

There is a good compatibility between two types of dam and support elements along the contact surface.

Thermal Loading and Boundary Conditions

Since Karun-1 is a high dam, water's temperature along dam elevation in reservoir is not constant and only water temperature at top elevation is equal to ambient temperature and
whatever we go lower, water temperature goes down. For taking into account the severe condition associated with high temperature gradient, the Summer season is considered for thermal loads simulation. Figure 6a-c shows temperature boundary conditions assumed in this research paper for considering the extreme conditions. It is worth to mention that these critical conditions are based on engineering judgment coincident with the instrumental reports (thermometers) located in dam body and obtained from water and power supply.

![Fig. 6. (a) Initial temperature conditions, (b) final temperature conditions and (c) difference temperature conditions](image)

![Fig. 7. Finite elements model of dam and its supports](image)
Authorization of Khouzestan province of Iran. Dam and support are tied to each other along the contact surface in ABAQUS program.

Along elevation at upstream face of the dam, a temperature change was assumed as an exponential function. In accordance of material properties, ABAQUS automatically perform the heat transfer. Height of water behind the dam has been considered as 180 m and meanwhile, weight of dam also has been applied.

**Analysis Type**

ABAQUS can perform two analysis types simultaneously: displacement and temperature analysis. In Fig 7, finite elements model of dam and support are depicted.

**RESULTS**

Three types of output results as displacement, stress and internal energy has been selected and shown as follows on upstream and downstream faces of the dam.

**Displacements**

The displacement component (U1), along the river, is shown in the Fig. 8. Table 5 shows the maximum displacements along the river in two case of analysis. These displacements as

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Maximum U1 (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without-temperature</td>
<td>+8.5</td>
</tr>
<tr>
<td>With-temperature</td>
<td>+3.5</td>
</tr>
</tbody>
</table>

![Table 5: Maximum displacement of dam body along the river](image)

**Fig. 8:** River alignment displacements without thermal effects
Fig. 9: River alignment displacements with thermal effects

Table 6: Maximum and minimum stresses

<table>
<thead>
<tr>
<th>Type of analysis</th>
<th>Location</th>
<th>Max. principal</th>
<th>Min. principal</th>
<th>Cantilever</th>
<th>Arch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without-temp analysis</td>
<td>Dam</td>
<td>1.00</td>
<td>-1.50</td>
<td>0.80</td>
<td>-13.0</td>
</tr>
<tr>
<td>With-temp analysis</td>
<td>Dam</td>
<td>0.20</td>
<td>-2.70</td>
<td>-0.26</td>
<td>-7.0</td>
</tr>
<tr>
<td>Without-temp analysis</td>
<td>Near abutment</td>
<td>8.50</td>
<td>-1.88</td>
<td>0.84</td>
<td>-2.4</td>
</tr>
<tr>
<td>With-temp analysis</td>
<td>Near abutment</td>
<td>8.33</td>
<td>-3.80</td>
<td>-0.30</td>
<td>-28.0</td>
</tr>
</tbody>
</table>

can be found from Fig. 8 and 9 occurred along the crest of the dam. Positive direction is assumed from upstream to downstream direction.

Stresses

Here, 4 categories of stresses will be examined: maximum principal stress, minimum principal stress, cantilever and arch stresses. The min and max values of these stresses are shown in Table 6. For instance arch and cantilever stress distributions are shown in Fig. 10 and 11.

Internal Energy

Internal Energy of the model for analysis without-temp and analysis with-temp is calculated by ABAQUS program and a graph for internal energy was drawn with program. Figure 12 shows this graph and in Table 7 internal energy values of two types of analysis are compared.
Fig. 10: Cantilever stress: (a) downstream and (b) upstream

Fig. 11: Arch stresses: (a) downstream and (b) upstream
DISCUSSION

As it has been persuaded thorough all of this research, we are going to evaluate the mechanical behavior of Karun-1 dam considering the thermal loadings. Regarding results, the following interpretations and discussions will be made:

With considering Fig. 8, 9 and Table 5, we can conclude that under effect of thermal loads in summer season, the middle part of crest of the dam which has the maximum displacement in river direction has a tendency to move in opposite direction of applied hydrostatic pressures. This means that the effect of thermal loads and hydrostatic loads is in contrast. From the values in Table 5, it can be deduced that when thermal loads are applied to model, the maximum displacement of the dam crest along river is decreased about approximately 60%. This is an interesting result which shows the significant effect of temperature induced loads on dam displacement behavior. This result is in agreement with the result was obtained by Léger and Seydou (2009). They showed in Fig. 6 that, in Summer the action of thermal loads leads to moving the crest of the dam toward upstream face.

By looking over the values shown in Table 6, it can be say that in overall point of view, the effect of thermal loads are in the way of degradation of both tensile and compressive principal stresses. This is a good effect from the engineering design point of view. Furthermore, these results show that under the effect of thermal loads in Summer we have a potential to crack development in downstream face of dam body near to abutment. This is coincident with the result which obtained by Marafpour et al. (2009). It is worth to mention that relatively big tensile stress values observed in dam-abutment line could not be real and may be appeared due to numerical errors.

Figure 12 and Table 7 are showing that under the action of thermal loads, Karun-1 dam saves the larger amount of strain energy. This may be interpreted from the stability point of view that the dam without the action of thermal loads has a more stable condition.
CONCLUSION

At the end of this study, it can be say that the proposed mathematical model which implemented for thermal analysis of Karun-1 dam could be considered as an applicable, relatively comprehensive and reliable model which shows the valuable effect of thermal loads on the behavior of this dam.

REFERENCES