Thermo-Statically Safety Control of Dez Dam under Unexpected Lake Level Reduction

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Abstract: Dez dam stability was examined due to unexpected decrease in its reservoir level by performing a 3D finite elements analysis. The dam as well as its foundation and abutments have been modeled in a relatively exact manner. Moreover, the vertical contraction joints were simulated in the analysis. Hydrostatic, gravity and thermal forces have been taken into account as the main load combinations. 10m reduction of reservoir level from normal water level of the dam reservoir was considered in the modeling and the possibility of initiate and development of cracks in dam body was investigated by means of monitoring of principal stresses. The obtained results revealed that no serious instability would occur in Dez arch concrete dam.

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1. Introduction

In Iran, there exist some limited relatively old concrete arch dams. One of them is Dez dam located in vicinity of Dezful city in the north of Khouzestan province. This dam has an important role in the life of its neighboring inhabitants. The electricity and water for drinking and agriculture of the populated Dez river downstream villages and cities are supplied by this dam. Dam has a double curvature arch shape and constructed from concrete material during 1958 until 1963. In that time, Dez dam with 203 meter height from its base level was one of the sixth high level dams in the world. Figure 1 shows a view of the dam. The thicknesses of the dam at the crest and base level are 4.5m and 27m respectively. The crest length is about 212m and the level of the crest measured from free level of the world's oceans is about 354m.

Figure1. View of the Dez Dam

The maximum operating level of the dam was designed 350m from free sea level which later has been increased to 352m because of the optimum operations and demands. Area of the reservoir is approximately 65 square kilometers and the minimum water level of the reservoir is 300m above sea level. The crest level of the outlets is 335m above sea level and the entrance level of the power plant tunnels designated as 275m above sea level. The electric power supplied by the dam is about 520 Mw. As usual, after a relatively long period of operation time, it is rational to think that the there is a need for Dez dam safety to be investigated under unexpected reservoir fluctuation. This unusual loading is defined here as hydro+ gravity+ thermal loads when the level of reservoir is equal to 10m below the minimum water level surface. According to literatures, after service life of several decades, a considerable percentage of existing concrete dams, illustrate some kind of deterioration. Based on the studies performed examining the causes of this phenomenon, the ASR (Alkali-Silica Reaction) and unusual extreme loading such as earthquake excitations and reservoir level fluctuations are the main reasons of this dam stiffness and strength degradation (Swamy and Al-Asali, 1988; Ahmed et.al., 2003; Pedro, 1999). Sometimes mentioned degradation is concomitant with the occurrence of local cracks in dam body which can be a threat for the dam safety. Holding this issue in mind, the main objective of this paper is to investigate the possibility of damage occurrence in Dez dam due to unusual reduction in its reservoir level about to 10m from the minimum water level of reservoir. The same research has been done recently for another important old concrete arch dam named Karun-1 (Labibzadeh et. al., 2010, Labibzadeh and Khajehdezfuly, 2010, Labibzadeh and Khajehdezfuly, 2010).

In this investigation, as well as the hydrostatic pressure of reservoir and dam weight, the thermal loads due to air temperature changes have been assessed in the modeling. Thermal loads has a major effects in arch concrete dam stability analysis (Sheibani and Ghaemian, 2006; Ardito, et. al, 2008; Léger and Leclerc 2007; Léger and Seydou 2009; Labibzadeh and Khajehdezfuly, 2010). Furthermore, for achieving the more and more accurate in analysis, the effect of vertical contraction joints in hydro-thermal simulation of the dam was taken into account. Even though the latter issue was no major challenge for dam engineers in their analyses and designs, this factor can affect the dam safety analysis results significantly (Labibzadeh and Khajehdezfuly, 2010). In the past recent years, the amount of the rainfall has been decreased considerably in Iran specifically in Dez dam water fall domain. Consequently, the reservoir volume of the dam has been reduced gradually. As the water level of the dam was decreasing, the safety controls of Dez dam became more important due to the increase in electric energy demands. Furthermore, the height of the sediment behind the dam has been progressively increased during the last four decades and this factor also reduces the volume of available water from the dam for use in drinking and agriculture. So, that would be the main reason for doing this study. The suggested research has been done by means of a relatively 3D exact simulation of the geometric, material behavior and boundary conditions of the dam. Principal stress tensors were selected as the basic stability indexes safety control and were examined. The special attention was paid on the effects of thermal strains occur in the dam due to the change in environmental temperatures during the year. It will be shown that under the reservoir level reduction up to 10m the possibility of initiate and development of cracks in downstream face of the dam exists.

2. Material and Methods

2.1. Material specifications

Table 1 summarized the material properties which have been inserted in finite elements analysis of the proposed model. These values have been derived from the authoritative reports of Khouzestan water and power organization.

Table 3. Material properties library used in the analysis

	Concrete Dam	Rock Support
Density (kg / m3)	2500	2000
Young's Modulus (MPa)	25480	40000
Poisson's Ratio	0.17	0.25
Conductivity	2.62	1
Expansion (1 / C°)	10e-6	9e-8
Specific Heat (C°)	1000	2000

2.2. Heat transfer

Heat flows from high-temperature regions to low-temperature regions. This transfer of heat within the medium is called conduction heat transfer. The Fourier heat conduction law for one dimensional system states that the heat flow Q is related to the temperature gradient $\partial T/\partial x$ by the relation (with heat flow in the positive direction of **x**), (Reddy, J. N., 1993):

$$Q = -kA\frac{\partial T}{\partial x} \qquad (1)$$

Where k is the thermal conductivity of the material, A is the cross-sectional area, and T is the temperature. The negative sign in the (1) indicates that heat flows downhill on the temperature scale. The balance of energy in an element requires that

$$-kA\frac{\partial T}{\partial x} + qA\,dx = \rho c A\frac{\partial T}{\partial t}dx - \left[kA\frac{\partial T}{\partial x} + \frac{\partial}{\partial x}\left(kA\frac{\partial T}{\partial x}\right)dx\right] \qquad (2)$$

Or

$$\frac{\partial}{\partial x}\left(kA\frac{\partial T}{\partial x}\right) + Aq = \rho c A\frac{\partial T}{\partial t} \qquad (3)$$

Where q is the heat energy generated per unit volume, ρ is the density, c is the specific heat of the material, and t is the time. The equation (3) governs the transient heat conduction in a slab or fin (i.e., a one dimensional system) when the heat flow in the normal direction is zero. The following metric units will be used:

T ; ˚C (Celsius)

k ; $Wm^{-1}{}^{\circ}C^{-1}$ (Watts per meter per degree Celsius)

q ; Wm^{-3}

ρ ; $kg\ m^{-3}$

c ; $J\,kg^{-1}{}^{\circ}C^{-1}$ (Joules per kilogram per degree Celsius or $m^{2}s^{-2}{}^{\circ}C^{-1}$)

It is important to note that since in this study, for the thermal analysis, the records of the thermometers installed in the different positions of the dam (mainly located in the central cantilever of the dam) are inserted directly into the finite elements model, so we have not considered the type of the heat transfer such as convection or radiation directly but in fact we have involved these effects indirectly in the analysis because that the temperatures which recorded by the thermometers have influenced by the all types of heat transfer mentioned before such as convection and radiations. This method of heat transfer analysis is called inverse (indirect) solution (Léger and Leclerc, 2007). The direct solution predicts the evolution of the temperature distributions from specified upstream and downstream temperature values. The inverse solution uses recorded temperature data at embedded thermometers to interpolate and extrapolate to the external faces the temperature field with due consideration of thermal wave attenuation and face shift with depth along a section (Léger and Leclerc, 2007).

2.3. Thermo-elastic Constitutive Relations

It is well known that a temperature change in an unstrained elastic solid produces deformation. Thus, a general strain field results from both mechanical (i.e. here hydrostatic and gravity loads) and thermal effects. Within the context of linear deformation theory, the total strain can be decomposed into the sum of mechanical and thermal components as (Sadd, M., H., 2005):

$$e_{ij} = e_{ij}^{(M)} + e_{ij}^{(T)} \qquad (4)$$

Where e_{ij} is the total strain tensor, $e_{ij}^{(M)}$ is the mechanical and $e_{ij}^{(T)}$ is the thermal part of strain tensor.

$$e_{ij}^{(T)} = \alpha_{ij}(T - T_0) \qquad (5)$$

In above relation, the α_{ij} is defined as coefficient of thermal expansion tensor. This coefficient for concrete was specified in table 1.

$$T - T_0 = \Delta T \qquad (6)$$

In relation (6) the ΔT

Is the thermal gradient which inserted into the model corresponding to the thermal records of the thermometers embedded in the Dez dam.

2.4. Method of using registered temperatures data

For achieving to relatively precision thermal analysis, the temperatures which recorded by thermometers thorough available period of time have been examined. The figures 2 to 11 show the variation in temperatures registered with instruments during the 1975 to 2007. The temperatures are presented in the ˚C (Celsius) unit and the period of each graph is equal to one year. The curves which observed from this graphs obtained through an exact regression.

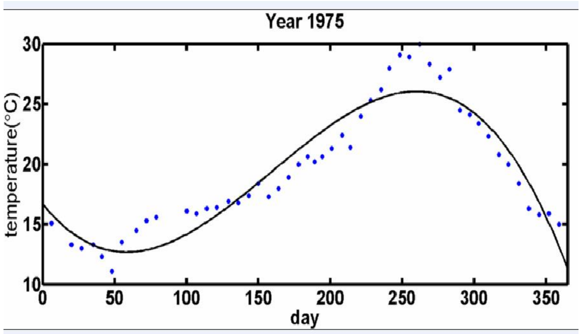

figure 2. Temperature variation in 1975

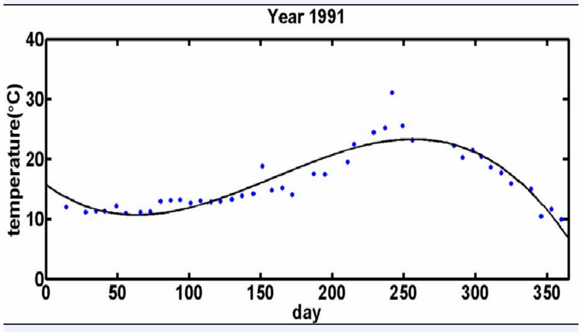

figure 3. Temperature variation in 1991

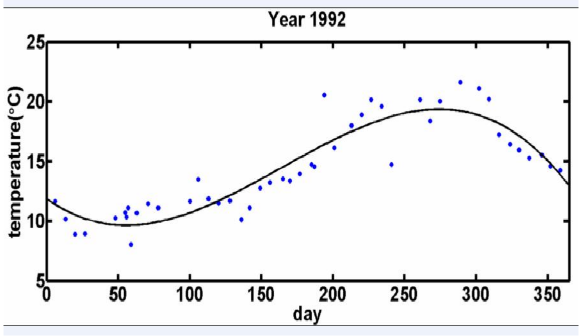

figure 4. Temperature variation in 1992

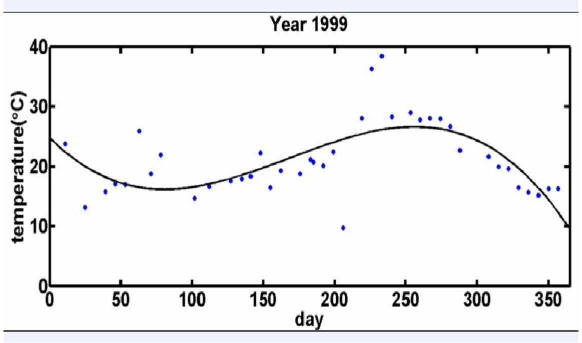

figure 7. Temperature variation in 1999

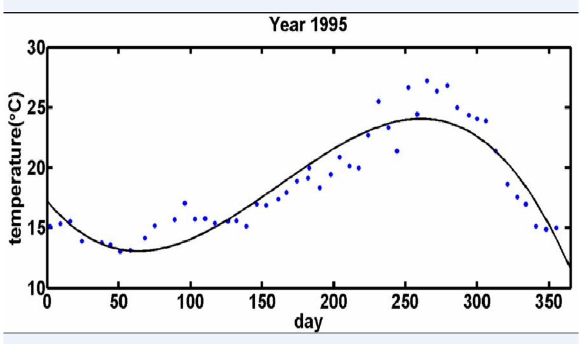

figure 5. Temperature variation in 1995

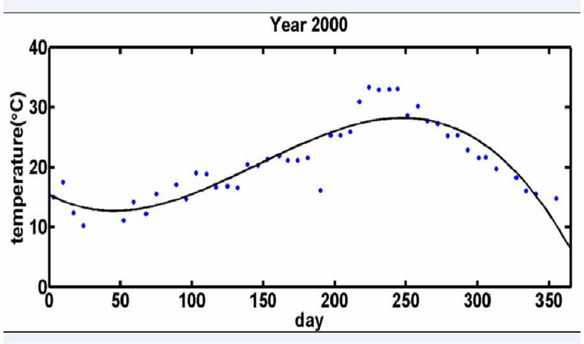

figure 8. Temperature variation in 2000

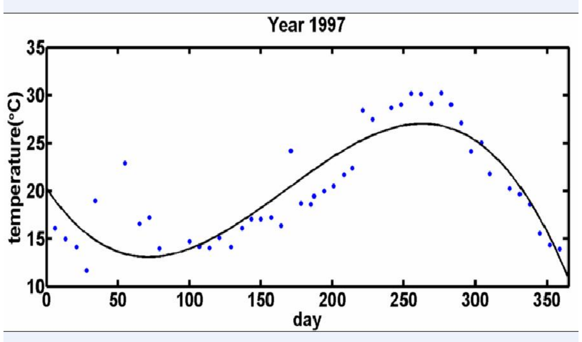

Figure6. Temperature variation in 1997

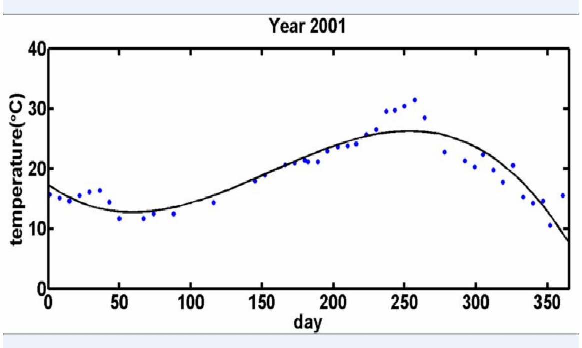

figure 9. Temperature variation in 2001

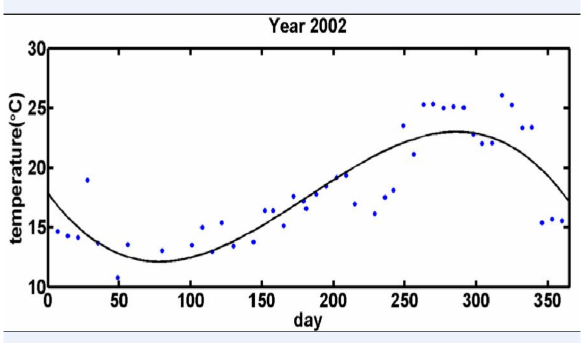

figure 10. Temperature variation in 2002

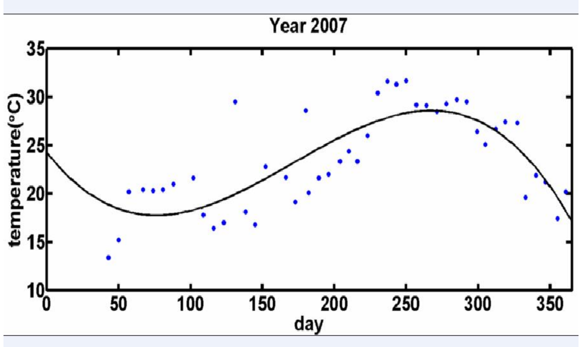

figure 11. Temperature variation in 2007

This temperatures recorded by thermometers which embedded in the central cantilever of the dam. Figure 12 shows the position of thermometers in the central cantilever. As it can be realized from these ten configurations, the shape of the variation of the temperatures in Dez dam body follows the sinusoidal function. This is a rational result, because the variation of the air temperature in the site of the dam according to the available weather forecasting data also varies as sinusoidal manner. This temperature change is similar to that reported by Sheibany and Ghaemian (2006). Based on the above temperatures, for the severe thermal effects condition to be considered in the analysis, the largest existed temperature differences in our time period (1975-2007) computed and inserted as iterance data to the finite elements model. The sequence of solution has been summarized as in figure 13. The results and their interpretations are brought in the next section.

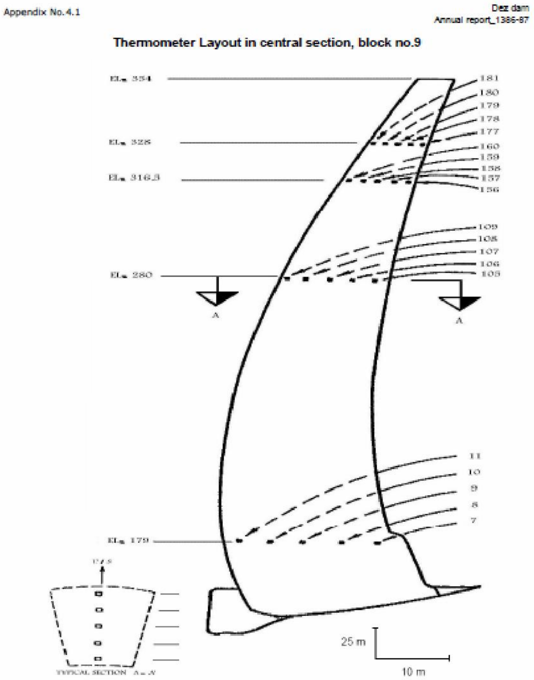

figure 12. Thermometers in central cantilever of Dez dam

3. Results and Discussions

Following the method described in previous section, the Dez arch concrete dam has been analyzed under the effect of 10m unusual reduction of its reservoir level from normal water level. The most dangerous situation which threatens the dam safety was obtained when the level of the lake came down to 290m above sea level. This means that the reservoir level reduces about to 10m from its minimum water level. The counters of dam displacements at this level have been shown in figure 14. The picture illustrates that the maximum deflection takes places in the middle of the crest of the dam and the value of this deflection is about to 4.02 cm which is accordance with the range of the records of pendulums of the dam registers the displacements of the dam. The negative sign in the values of the deflections means that these deflections have tendency towards the upstream face of the dam. This is the opposite direction which hydrostatic loads like to move the dam toward it. So it can be concluded that the effect of thermal loads in this level of the reservoir is greater than the effect of other main source of loads such as hydro and gravity forces. For investigate the possibility of occurrence of cracking phenomenon in the dam body, the maximum principal stresses are displayed in the figure 15.

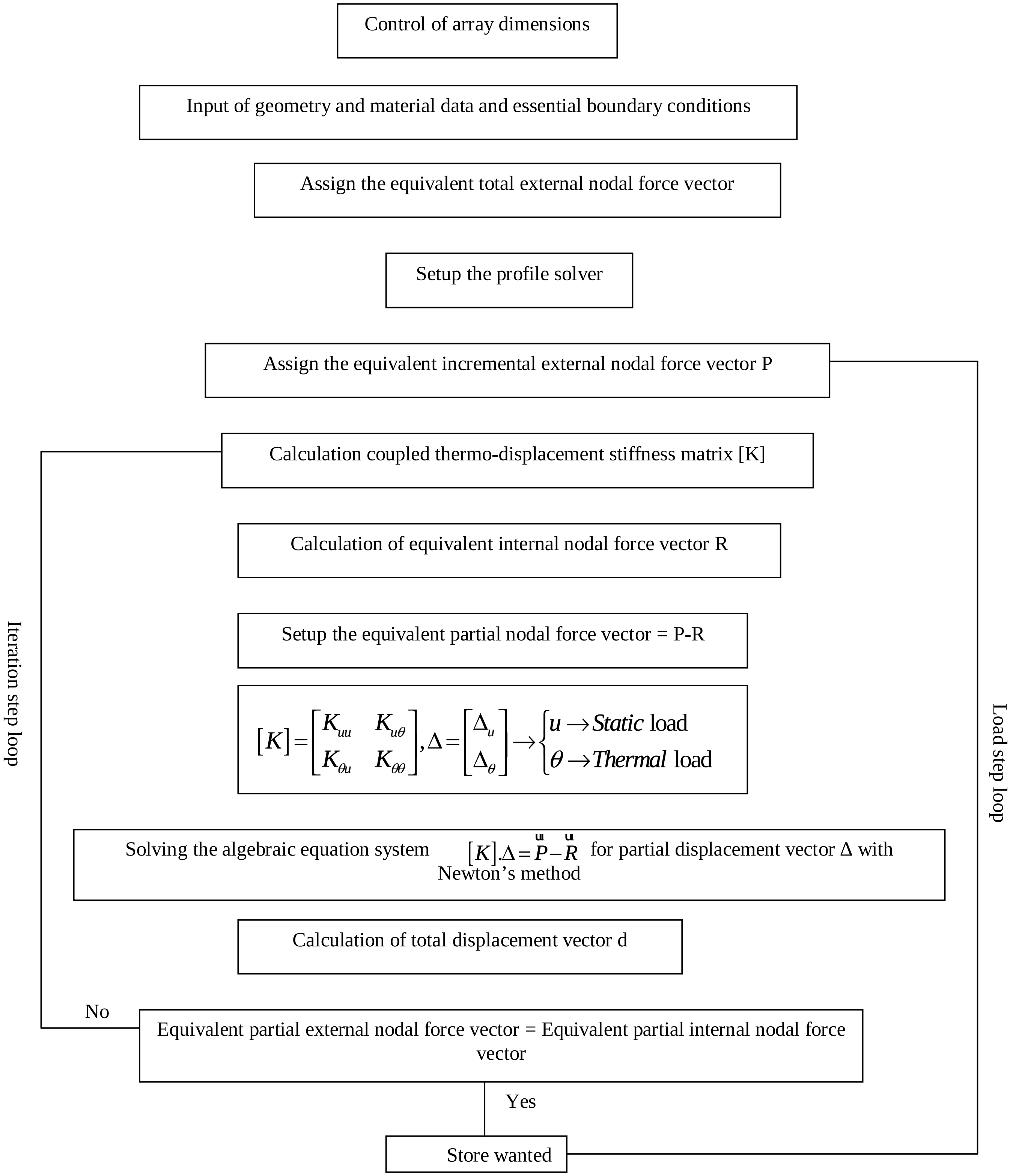

Figure13. The numerical solution of proposed problem

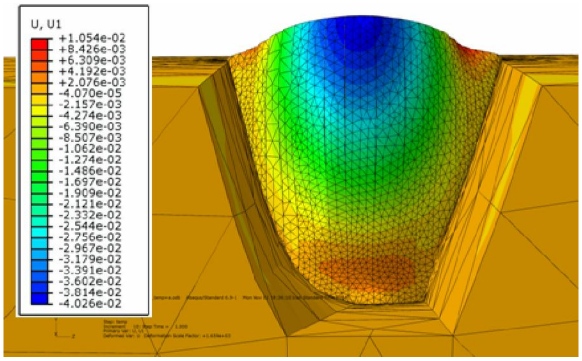

Figure 14. The Dez dam deflections: the reservoir level= 290m

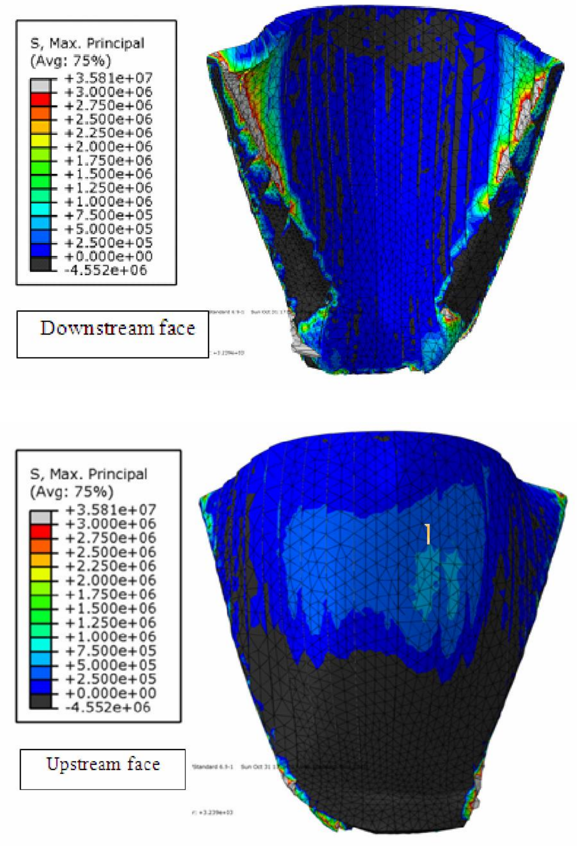

Figure 15. The Dez dam deflections: the reservoir level= 290m

In the figure 15 the color of maximum principal stresses which are greater than 3.0 MPa has been selected as grey. We can observe from this picture that only a limited area in the downstream face of Dez dam near the abutments has tensile stresses greater than 3.0 MPa (assumed the tensile strength of dam concrete material) and there a potential for cracking. However these stresses do not penetrate through the thickness of the dam so we should only strengthen the layers of concrete near the downstream surface. So, author of this paper suggests that the operation of the dam should be organized in such a way that water level of reservoir varies between max and min water level and reduce level of water of the reservoir about to 10m below the minimum level should be avoided.

4. Conclusions

After reviewing the results of stress analysis under thermal and mechanical loadings of Dez arch concrete dam it was cleared that the unexpected reduction of the reservoir level dam about to 10m below the minimum water level can be the source of cracking on downstream face of the dam in tensile mode and such a reduction should be avoided by proper operation programming.

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