# Numerical Modeling of Creep Phenomenon in RCC Dams and Evaluation of its Behavior Using FEM

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**Abstract**

This study have revealed that the estimation of specifications of concrete aggregates at early times is necessary for the analytic calculation of thermal stress and the cracks related to that in the structure of mass concrete. The experiments have shown that the measurement of concrete creep at early times is a difficult and complex work because the intended sample is creeped after loading. This affair makes the separation of elastic strain from the strain resulted from the creep relatively difficult.

In addition, the safety of structures against natural disasters is of significant importance. This importance is ranked based on the structure kind. The safety of the structure importance when it has considerable physical and financial damage after the demolition. For instance, the long structures that can accommodate a large number of population should enjoy a high level of safety. The dams are of the structures the safety of which is important and might have irreparable physical and financial effects after demolition. The concrete dams with their vital role concerning the presentation of an endless life-long service and the intensity and scale of dangers that can be created by the emergence of every kind of problem or damage to the dam are of significant structures that should be evaluated in terms of safety. Whereas the creep is effective at the level of internal stresses of concrete dam, in the present research, this effect on the rolled concrete dam is studied and the rolled concrete Jegin Dam has been selected as the case study. The results show that the creep has a considerable effect on the behavior of dams. Considering the effect of creep causes the increase of changing the places along either the ordinate or the current. Furthermore, this affair causes the reduction of internal stresses and the release of stress.

**Keywords: RCC Dam, Finite Element Method, Creep, Norton Creep Law**

## 1. INTRODUCTION

The evaluation of existing dams is of important matters in the case of dam building in all of which the phenomenon of creep has occurred. Therefore, determining a sufficient model for providing the effect of creep on the internal stresses can be resulted in the very appropriate evaluation of safety status and structural stability of existing dams. The creep is an intricate phenomenon that is happened at the time of loading in the concrete. Bazant describes the creep as the most indeterminable mechanical specification of concrete [1]. When loading the concrete, a deformation occurs that can be divided into two steps: rapid deformation and deformation depending on time that is, begins rapidly but it continues for several years; this is recognized as the creep [2]. Some cracks may appear on the foundationof mass concrete after long-term utilization that might be created for the reason of change of volume resulted from the condensation of concrete; this phenomenon is recognized as the condensation [3]. The dryness resulted from the condensation in the mass concrete is primarily developed for the reason of unequal distribution of moisture. The condensation also causes the development of various strains in different segments of concrete components of structures. The exact evaluation of the amount of concrete condensation is of significant importance for designing the pre-stressed concrete and anticipating the crack in the mass concrete. The primary behavior of concrete is based on the multi- dimensional and polyhedral complex phenomena. The calculation of risk of crack and residual stresses in the concrete structures has been difficult and it is still a considerable subject. The concrete behavior in early times is generally described as viscoelastic behavior [4].

The analysis of deformation of hardened concrete during the time has been the purpose of many studies done during the recent years and many experimental equations have been developed for the calculation of time-dependent behavior of concrete. Although the phenomenon of creep exists in many materials, at least, there are two fundamental differences between the concrete and the other usual building materials. First, the concrete is a heterogeneous material with regard to the cement gel, crystal products of hydration, water, hydrate and grain cement and also is considered as a non- isotopic material, when it is reinforced; second, the cement specifications vary depending on the durability, heat, relative moisture and its application in the place. The condensation and dilation cause the creation of gradual stresses in the concrete and the condensation causes the increase of the amount of creep [5].

So far, many studies performed in regard of concrete creep. Artatari and You (1967), with experiment on the plastered concrete slab at different temperatures, revealed that the creep is increased by the increase of temperature and the increase of concrete life now of load- carrying causes the decrease of creep speed. Furthermore, they revealed that by the increase of temperature, the amount of reversible strain at the stage of load- removal is not considerably increased [5].

Easton and Sounders (1973), by testing the torsion on the samples of gasket cement under the temperatures between 25˚C and 90˚C, concluded that if the temperature cycles were created during the operation of stress on the sample, the sample's strain is considerably increased in the first cycle, and no considerable increase is observed in the creep in the next cycles [8]. They presented a model for estimating the concrete creep at different temperatures in 1974. In this model, an equation was introduced for the calculation of the amount of sudden creep resulted from the increase of temperature, too. Furthermore, they expressed that, based on the accomplished experiment, if the temperature of concrete sample before the load- carrying are increase from 20˚C to 70˚C for two hours and then, the sample's temperature is reduced to 40˚C; and after a time, the creep test will be done on the sample, when the sample's temperature is increased from 40˚C to 58˚C, sudden increase is not observed in the amount of creep. When the sample's temperature is increased from 58˚C to 76˚C during the load- carrying, a sudden increase is occurred in the creep [9]. These researchers did not state any reason for this matter.

Jouy (2004) presented a numeral model for assimilation of the behavior of concrete of RCCD dams that the stress- strain relationships with multi- layer structure has been model for the description of elastic and elastoplastic behavior. As a practical sample, Finite element model of Longtan Dam with four different mix design from rolled concrete with different resistance properties in different parts of body was analyzed. It is worth mentioning that the mass concrete is used in the section of connection of the dam with the foundation.

## 2. MATERIAL AND METHODS

### 2.1. CREEP

The creep is the specification of concrete because of which, the concrete is constantly deformed because of long- term loads under fixed stress that is at the acceptable range of elastic. By the increase of load- carrying time, the amount of non- elastic deformation is increased, too; and the total amount of that may be several times of short- term deformations of elastic. However, in the course of time, the speed of increase of deformation is decreased and the increase curve would have asymptote.

Hence, and because of the majority of data present about the creep have been obtained with the assumption of the collectability of the effects of the creep and condensation, in the present project, the creep would be regarded as a deformation exceeded from the condensation [5].

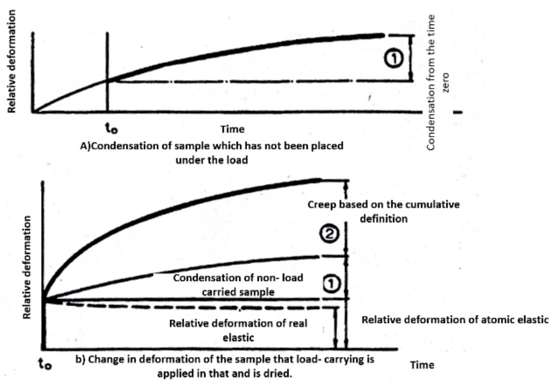



**Figure 1. Time-dependent deformations in the concrete under a constant load**

Although the creep is a phenomenon separate from the condensation, these two phenomena are studied together. There are many relationships for predicting the creep. Because of many variables, the exact prediction of creep is complex; but a creep coefficient can be represented under a standard situation as a standard creep coefficient [13].

$$\text{Ct} = \frac{creepstrainatt \quad hetimet}{earlyelastics \quad train} = \frac{t^{0.6}}{10+t^{0.6}} \text{ Cu} \qquad (1)$$

The creep is considered as one of the non- linear specifications of materials in the analysis. This program divides the creep phenomenon into three parts. The first stage is the primary creep; the second stage is the secondary creep; and the third stage is the final stage of the creep (Figure 2). The ANSYS program can model first two stages and the third stage is disregarded due to the probability of calculating mistakes.

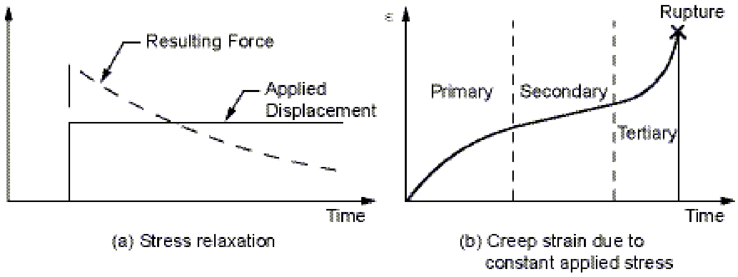



**Figure 2. Stages of creep simulation in ANSYS**

The first method is an implicit method. Themethod that is used for the analysis of creep is a strong, fast and exact method that is suggested for the general application of problem of solution of creep. This method can apply the effects of temperature in the procedure of problem solving. The implicit method uses the Backward Euler Integration for the calculation of creep strains. This calculating method in a numeral form is stable under any condition.Therefore, it does not require very small temporal steps and this affair causes the increase of the speed of problem solving by this method. The important point of this method is that an appropriate number of temporal steps be considered in the procedure of problem solving to get the exact answers.

In modeling the creep, Norton's equation is used for modeling the creep behavior of the concrete that is expressed as following:

$$\dot{\varepsilon}_{cr} = C_1 \sigma^{C_2} e^{-C_3/T} \qquad (2)$$

$\dot{\varepsilon}_{cr}$ = changes in creep strain based on time

σ= equivalent stress

T= temperature

t= time at the end of every temporal step

The coefficients of C are empirical amounts.

## 2.2. JEGIN ROLLED CONCRETE DAM

Jegin dam is constructed in the south- east of Iran in Hormozgan province. This dam is placed on Jegin River about 61 km away from the north- east of Bandarjask city.

**Figure 3. view of rolled concrete Jegin Dam**

**Table 1. specifications of Jegin Dam**

| **Dam type** | RCC |
|---|---|
| **Height from foundation** | 78m |
| **Crest length** | 253m |
| **Crest width** | 5m |

**Table 2. specifications of RCC used in Jegin dam**

| | **RCC1** | **RCC2** |
|---|---|---|
| **Tensile strength (GPa)** | 1.5 | 1.2 |
| **Modulus of elasticity( (GPa)** | 22.5 | 20.2 |
| **Fraction energy (N/m)** | 100 | 86 |

| | |
|---|---|
| **Foundation width** | 63m |

| | | |
|---|---|---|
| **Poisson's coefficient** | 0.2 | 0.2 |
| **Density (kg/m$^3$)** | 2450 | 2450 |

It is obvious in Table 1 (geometry of the biggest block of Jegin dam) and Table 2 that RCC1 with higher resistive features in comparison to RCC2 has applied in a part of the section placed on the upstream of the dam. These materials are executed in the lateral section variable between 1 to 1.5 meters. Therefore, in the finite element model, the specifications of RCC1 concrete has regarded for the elements placed between the upstream of dam up to 1.5 m.

## 2.3. FINITE ELEMENT MODEL

The two-dimensional finite element model of the dam is analyzed in two states. The first state that only the dam body is modeled and the second state in which the perfect model is the dam- foundation- reservoir.

The four-node cubic element of PLANE42 with 2 degrees of transfer freedom per node is used for mesh generation of the dam body and the foundation that is also able to model the creep. The general diagram of these elements are represented in Figures4 and 5.

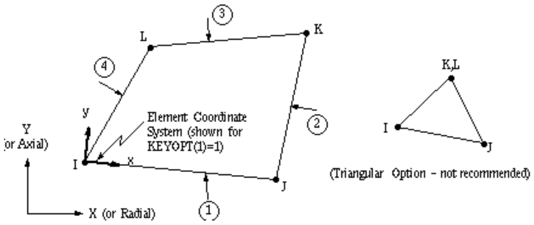



**Figure 4.4-node PLANE42 solid element**

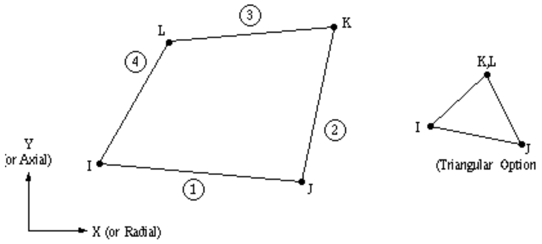



**Figure 5.4-node FLUID29 fluid element**

The 4-node solid element of FLUID29 with 2 degrees of transfer freedom and 1 degree of pressure freedom per node is used for modeling the reservoir and the ability of application of hydrostatic and hydrodynamic loads (Figure 6). The pressure on the free surface of the reservoiris assumed zero. The border status of the end layer of reservoir is considered for the total absorption of the hydrodynamic wave.

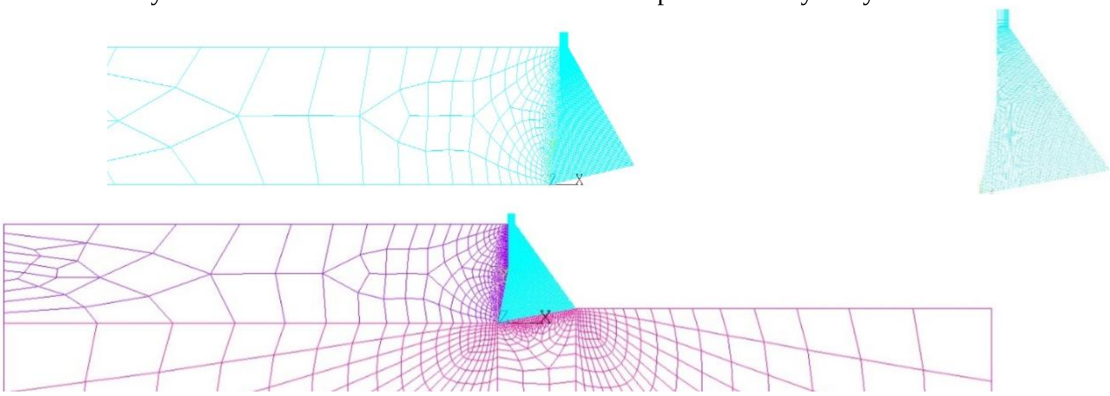


**Figure 6. Finite element models used in analysis of a) dam body, b) dam and reservoir, c) dam, foundation and reservoir.**

## 3. RESULTS OF NUMERICAL ANALYSIS

The purpose of non-linear static analysis of JeginRCC dam is the evaluation of the safety status of the dam body in the static conditions. For this purpose, the two-dimensional model of the finite element was prepared for the dam body and the base with regard to the reservoir and the analysis by ANSYS software. At first, the effect of creep on the dam body and in the empty reservoiris taken into account. Then, the dam, reservoir and foundation are studied. The models studied in this research is presented in Table 3.

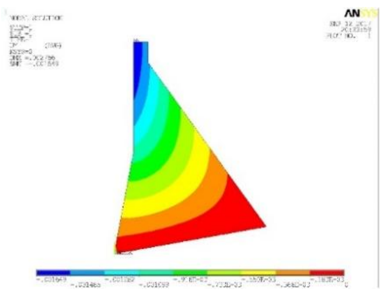
**Table 3.Summary of analyses specifications**

| No. | Analysis type | Creep effect | Reservoir | Foundation |
|---|---|---|---|---|
| **1** | Static | no | no | no |
| **2** | Static | yes | no | yes |

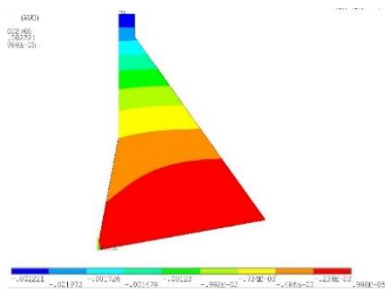
| | | | | |
|---|---|---|---|---|
| **3** | Static | no | yes | yes |
| **4** | Static | yes | yes | yes |

## 4.1. EMPTY RESERVOIR WITHOUT CREEP EFFECT (NO.1)

This analysis aims to study the effect of creep on the behavior of rolled concrete dam in the situation in which the reservoir is very vacant and the dam is affected only by its weight. In Figure 7, first, the transposition in both directions of perpendicular on current and the current for both states without creep and with creep have been presented; and, in the following, the maximum distribution of tensile stress and pressure stress have been represented.

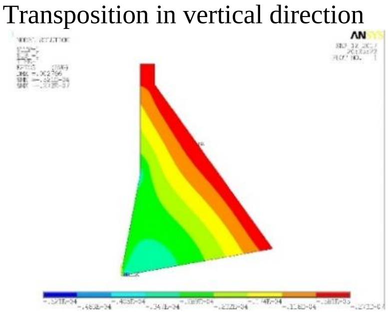


Transposition in vertical direction

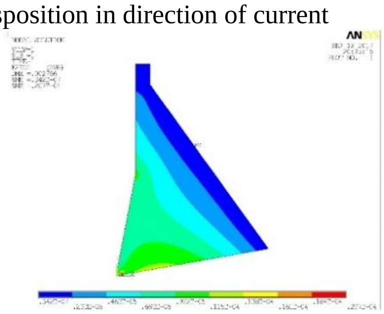


transposition in direction of current

transposition



Maximum pressure strain



Maximum tensile strain

Mechanical strain

**Figure 7. Results of numeral analysis for No.1**

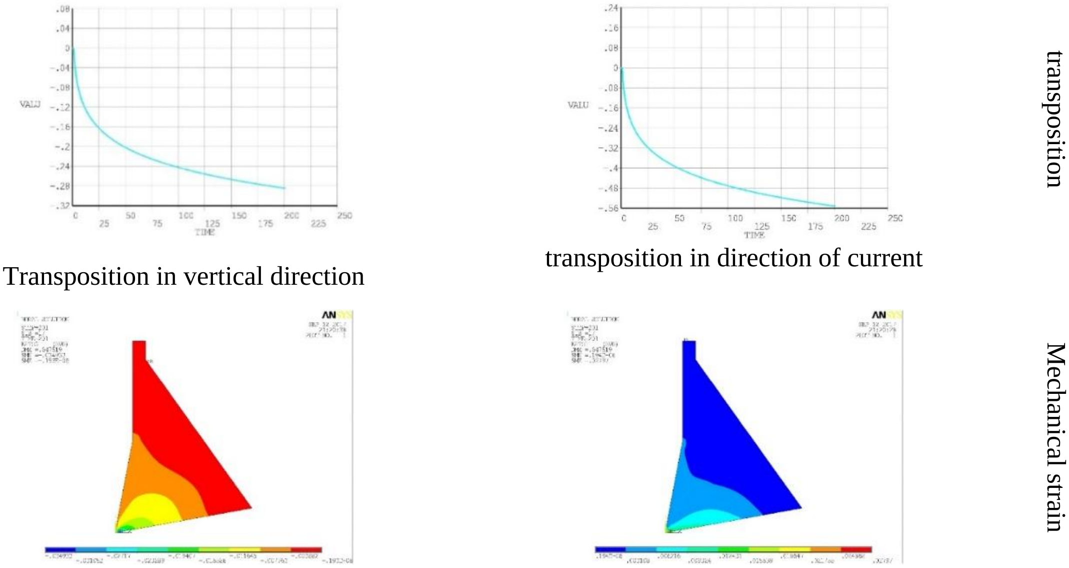
According to the geometric form of the dam and this considering that the dam is affected only by its weight, it can be expected that its lateral transposition to be very few that, with regard to the obtained results, its amount is about 2.2 cm which happened in the dam crest. Furthermore, the amount of transposition (about 1.6 cm) in the vertical direction which is the prevailing transposition of the dam body corresponds to the results obtained from the studies done by Gaemian et al [23]. Also, with regard to the load- carrying condition, the amount of tensile stress is slight and the tensile stress of few points reaches about 0.7 MPa. Moreover, the most amount of pressure stress is observed in the heel of the dam.

## 4.2. EMPTY RESERVOIR WITH CREEP EFFECT (NO.2)

In this state, the creep model which had been calibrated and validated, has been used in the modeling and the obtained results have been presented as followings. It is reminded that the creep effect is revealed during the time linger than the time at which the dynamic load reveals its effect; and considering this fact that 90 percent of deformation of mass concrete that has been resulted from the creep is revealed after 200 days, so, the reduction of calculating load from 200 days load- carrying has been applied in this analysis. Furthermore, in the following, a comparison would be done between the results obtained from the static analysis of dam.

The amounts of stress and strain transposition for the dam body with vacant reservoir and with regard to the creep effect is presented in Figure 8. The amounts of transpositions, in comparison to the former state in which the creep effects have not regarded, indicate a considerable increase. The amount of transposition in the direction of current is about 56 cm and its amount in the vertical direction is 9 cm. It should be regarded that these amounts in the former state were less than 3 cm.

The amount of maximum tensile stresses is also about 0.8 MPa that is less than the tensile stress of concrete and, in comparison to the former state (without regarding the creep) reveals a few increase about 0.6 MPa. The maximum pressure stress in this state is about 1.6 MPa that reveals a reduction about 0.6 MPa in comparison to the former state. Furthermore, the maximum tensile and pressure strains in this state have increased in comparison to the former state, the amounts of maximum tensile strains become about 0.028, and the amount of maximum pressure strains is 0.035, too.




Transposition in vertical direction

transposition in direction of current

Maximum pressure strain

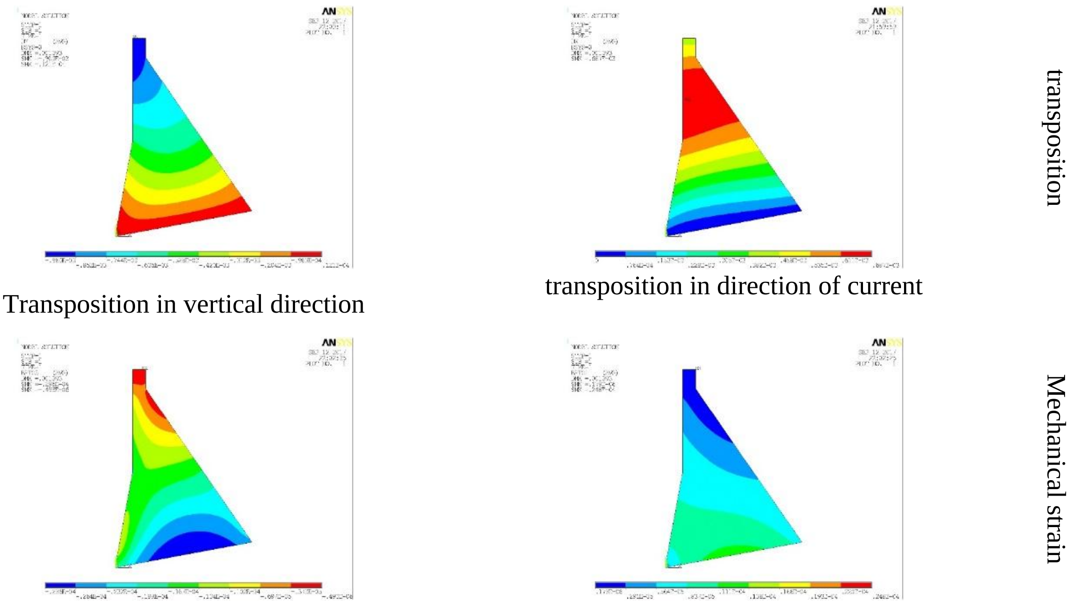
Maximum tensile strain

**Figure 8. Results of numeral analysis for No.2**

### 4.3. FULL RESERVOIR WITHOUT CREEP EFFECT (NO.3)

The accomplished researches reveal that the balance of water of Dam Lake affects the frequencies and the form of natural flows [4]. The other researches done on different dams in Japan has revealed that the base period in the state of the vacant lake is almost half of the state of the filled lake. This amount remains approximately fixed until when the water level on lake reaches 60% of its maximum balance amount [4].

The reaction of the dam in the occurrence of an earthquake is considerably affected by the lake water. The studies done on Saveh Dam (with 105 m height) in Iran reveals that, with regard to the geometric effects of the dam and lake and in the state of non- compressible water, the obtained results are less than the state of compressible water. Furthermore, it was observed that when the bulk modulus of water became smaller, the structural reaction is delayed and the maximum amount of velocity and reaction diagram of structure becomes flattere [4].




Transposition in vertical direction

transposition in direction of current

Maximum pressure strain

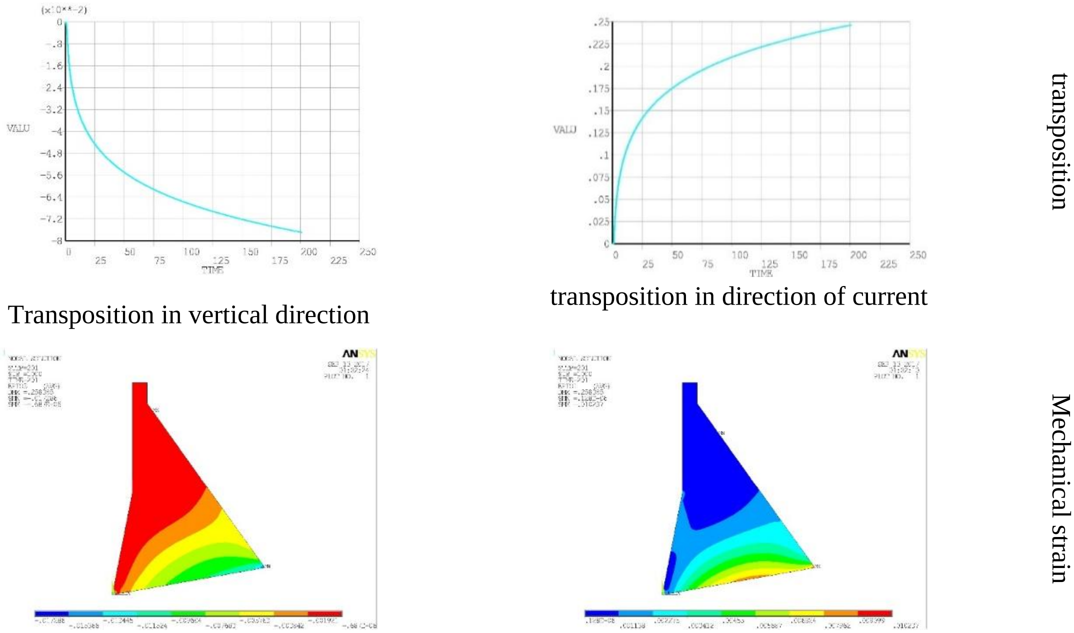
Maximum tensile strain

**Figure 9. Results of numeral analysis for No.3**

In this case, the reservoir is modeled and its border status has been provided. It should be considered that the creep effect has been disregarded in this state and only the load of weight, hydrostatic and hydrodynamic pressure are the external powers operated on the dam body.

## 4.4. FULL RESERVOIR WITH CREEP EFFECT (NO.4)

In this state, in addition to modeling the filled reservoir, the creep specifications of concrete of the dam body have taken into account in the modeling, too. The hydrostatic pressure, transpositions in the vertical and horizontal directions, main stresses and strains have represented in Figure 10is compared with other states. The amount of hydrostatic pressure in this is similar to the former state and it is obvious that the pressure does not change; because the hydrostatic pressure is independent from the creep effect and depends only on the height.




Transposition in vertical direction　　transposition in direction of current

Maximum pressure strain　　Maximum tensile strain

**Figure 10. Results of numeral analysis for No.4**

The amount of transposition in this state in the direction of current and in the vertical direction is 25cm and 8 cm, respectively. This amount in both directions is more than the state in which the creep disregarded that its reason is the creep effect in two directions. Its amount is also more than the second state in which the creep effect had been disregarded and this confirms that the hydrostatic load of the reservoir which is in the lateral direction, has a considerable effect on the vertical transposition, too. In Table 4, the amount of interval of changes of outputs obtained from the static analysis of the Jegin dam under different conditions of loadingis summarily presented for better comparison.

**Table 4.Summary of results of creep analysis of JeginRCC dam**

| | | State 1 | State 2 | State 3 | State 4 |
|---|---|---|---|---|---|
| **Transposition in direction of current** | Max | 0 | 0 | 0.07 | 0.25 |
| | Min | - 0.02 | - 0.56 | 0 | 0 |
| **Transposition in vertical direction** | Max | 0 | 0 | 0.1e - 4 | 0 |
| | Min | - 0.02 | - 0.32 | - 0.9e -3 | - 0.08 |
| **Maximum tensile stress** | Max | 714312 | 798029 | 847161 | 609652 |
| | Min | 0 | 0 | 0 | 0 |
| **Maximum pressure stress** | Max | 0 | 0 | - 20814 | - 21965 |
| | Min | - 0.22e7 | - 0.16e7 | - 0.13e7 | - 0.13e7 |
| **Maximum tensile strain** | Max | 0.2e - 4 | 0.03 | -.2e - 4 | 0.01 |
| | Min | - 0.34e- 7 | 0.2e- 6 | 0.2e- 6 | 0.13e- 6 |
| **Maximum pressure strain** | Max | - 0.3e- 7 | -0.6e -6 | -0.5 e- 6 | - 0.68e -8 |
| | Min | - 0.5e - 4 | - 0.03 | - 0.3e- 4 | - 0.017 |

## 4. CONCLUSIONS

In this study, the effects of foundation, reservoir and the method of application of creep in the rolled concrete dam were studied. Jegin Dam was modeled with regard to the interaction of dam, foundation and lake in the two- dimensional space in the introduced software and the seismic and static analyses were applied by the use of creep equations in ANSYS program. The lake was considered compressible and the foundation was regarded without mass. In continue, the results obtained from this thesis and some suggestions are presented for future researches.Norton's creep model has an appropriate ability for modeling the creep behavior of compressed rolled concrete dams. The stress and strain results are concordant in the analyses; but, in some cases, the maximum tensile strain represents obviously the conditions of materials. 200 day load- carrying is an appropriate time for evaluating the creep effect of the rolled concrete. The existence of creep effect in the state in which the reservoir and foundation do not exist, has many effects on the transpositions and freedom of stresses and most of these transpositions are in the vertical direction and for the reason of the body weight.In all cases of the static analysis, regarding that the creep has caused a considerable increase in the amount of transposition, both pressure and tensile main strain have increased.

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