CREEP BEHAVIOR OF THE CLAY CORES AT THE BOUGDOURA DAM USING ANSYS SOFTWARE

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ABSTRACT:

The creep of fine soils is due to the viscous properties of the assembly of mineral particles accompanied of adsorbed water which forms intergranular skeleton. It is evident during the secondary consolidation that the effective stresses are constant, the deformation extends over time. Rock fill dams with clay sealing cores deformed during exploitation. During commissioning of the core, clay undergoes. Creep is a major characteristic of the nonlinear behaviour of materials, in which the material continues to become deformed under a constant load. It can cause considerable deformations of the works (two to three times instantaneous strain in three years). This study presents a prediction of the creep behavior of a clay core in a rock dam subjected to constant hydrostatic loading for 20000 h and describes a procedure for modeling the primary and secondary creep law simulation using ANSYS software APDL In this aims, we have applied the finite element method based on a model shown in equation 8 called (Strain Hardening Model) in order to simulate a creep behavior of clay core.

1. INTRODUCTION

Deformation of soil involves time dependent structural rearrangement of the material due to its particulate nature. Basic laws describing the behavior of ideal continuum do not account for the structural rearrangement of the material and thus presents difficulties when applied to soils. Creep is a major characteristic of a nonlinear behavior of the materials, in which the material continues to become deformed under a constant load; it can cause considerable deformations of the works (2 to 3 times instantaneous strain in 3 years). Creep is a performance-based behavior since it is not an intrinsic materials response. Furthermore, creep is highly dependent on environment including temperature and ambient conditions. Creep can be defined as time-dependent deformation at absolute temperatures greater than one half the absolute melting.

The following creep equation developed by (Dorn, J. E. 1957) for metals and adapted to soil creep by (Noble, J. J. and T, Demirel. 1969) was employed to study time deformation behavior of clay soils:

$$\dot{\gamma} = A.e^{-\frac{\Delta H*}{KT}}.e^{\beta\tau} \qquad (1)$$

where:

$\dot{\gamma}$: Shear strain rate
A: Proportionality constant
ΔH*: Activation enthalpy
B: Stress factor
τ: Shear stress
K: Boltzmann constant
T: Absolute temperature

In the derivation of the equation, the following assumptions have been made (Noble, J. J. 1968):

- Clay particles are bound to each other by chemical bonds (including van der Waals bonds).
- The shear resistance of clay soils is due to existence of an energy barrier (activation energy) between the bonding units.
- Displacement of a bonding unit occurs when it surmounts the activation energy.
- The magnitude of the activation energy is equal to the energy of the chemical bond minus the mechanical energy absorbed by the bonding unit during deformation.
- The energy necessary to surmount the barrier is supplied by the thermal motion of the bonding units.

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- The resultant strain rate, y, is proportional to the number of bonding units which have thermal energies equal to or greater than the activation energy.
- The number of bonding units having energies equal to or greater than activation energy is given by Maxwell-Boltzman distribution law.

The pre exponential term. A, in Equation 1 includes the proportionality factor (frequency factor) relating number of activated bonds to strain rate and the activation entropy which can be related to the relative degree of order ness of the bonding units undergoing the flow. The stress factor, β, is equal to " $\frac{\beta\prime}{KT}$ " in which β' is identified as the flow volume. The product β'τ corresponds to the mechanical energy acquired by each bonding unit when the rupture of a bond is followed by a displacement. The term β' is a product of average bond area times the average distance moved by a bonding unit when displaced, and therefore has the dimension of volume.

This parameter gives quantitative description of flow mechanism. The term AH* is related to the bond energies involved in deformation process and reflects the strength and nature of bonding in clay soils. A primitive and real creep behavior model will be described here to define a reference state for stress-strain-time behavior of a real clay water system analogous to description of ideal gases or real solutions as opposed to real gases or real solutions (see figure 1), the shear rate decreases over primary stage up to the inflection point I, then starts to increase in the tertiary stage.

The experimental creep curves at low shear stresses show only a primary creep region which follows an initial deformation; then deformations terminate with time. At relatively high stresses (exceeding some limiting value) the curves are divided into three portions: primary, secondary and tertiary regions where shear rate decreases, remains constant and increases with time, respectively. In many instances secondary creep does not occur (Campanella, R. G. and Y. P. Vaid. 1974, Noble, J. J. 1968).

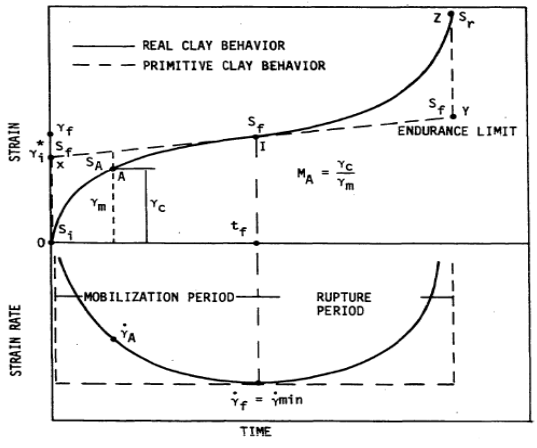


Figure 1. Creep Curve of real and primitive clay behavior (Erol, Orhan, 1977)

where:

γ_c Creep strain
γ_m Primitive Model Strain
M_A Mobilisation ration at "A"
$\dot{\gamma}_f$: Strain rate at inflection point
γ_I Initial adjustment strain
Si Initial soil structure
S_f Soil structure at Flow
S_A Soil structure at "A"
Sr Soil Structure at Rupture
γf, tf Time and strain at "I"

Classically, creep deformation is separated into three distinct stages, primary, secondary, and tertiary creep as depicted in figure 2. In the initial stage, or primary creep, the strain rate is relatively high, but slows with increasing time. This is due to work hardening. The strain rate eventually reaches a minimum and becomes near constant. This is due to the balance between work hardening and annealing (thermal softening). This stage is known as secondary or steady-state creep. This stage is the most understood. The characterized "creep strain rate" typically refers to the rate in this secondary stage. Stress dependence of this rate depends on the creep mechanism. In Third Stage, a microstructural damage mechanism occurring during creep can be manifested in a number of ways, such as micro cracks, cavities, voids, etc. in increased scale.

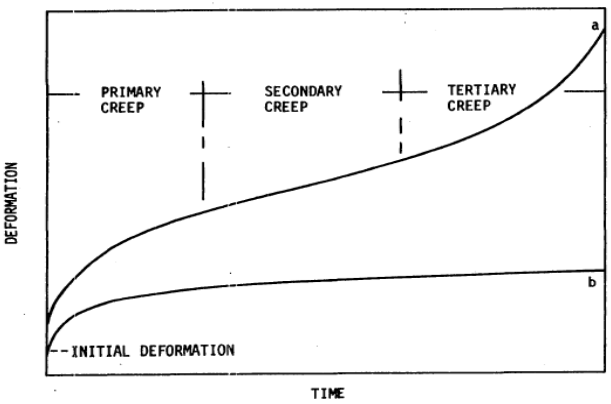


Figure 2. Creep stage strain from soil clay (Erol, Orhan 1977)

2. DAM DATA

2.1 Situation

The Souk N'Tleta dam project, whose capacity is 98 Hm3 and a height of 95m dike, will be built on the Bougdoura wadi at 8 km south of the city of Tizi – Ouzou. The structure dam is classified in the embankment zone type, and a crowning length is approximately 156m. The dam embankment will be made of loose geomaterials with:

- central core in clay colluvium.
- upstream recharge in gravelly-sandy alluvium (0/200)
- recharge downstream in sandstone blocks (0/200)
- upstream face consisting of limestone blocks
- the downstream protection will be carried out in vegetated soil

Figure 3 and figure 4 illustrate the cross section and the emplacement core clay within the dam embankment which is characterized by:

- A height of 95m.
- A rating of the ridge: 130.70 NGA
- A crest length: 156 m.
- A width of the ridge: 10 m

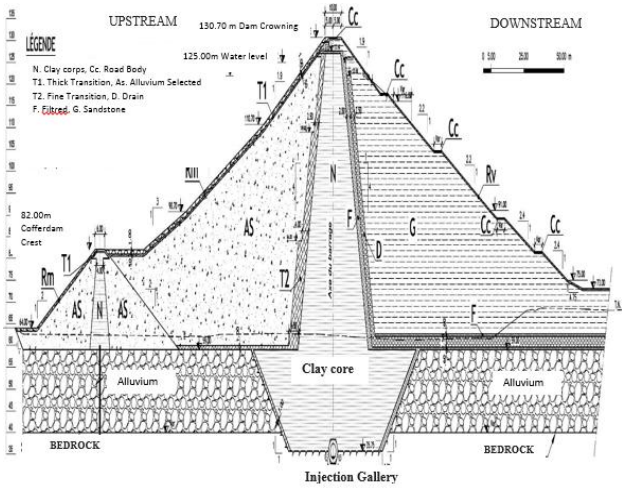


Figure 3. Cross section of the Bougdoura embankment dam (source NADT of Tizi-Ouzou, 2013)



Figure 4. Clay core emplacement within the dame (source NADT of Tizi-Ouzou, 2013)

2.2 Site geological formation

The geology of the site highlighted during the ADP, was largely confirmed during the excavation of the works. Located of the edge the Kabylian crystal massif, the site consists of shale Palaeozoic substratum with a general slope of 10° to 15° downstream on the roof the main complementary findings or modifications to be made to these descriptions are the absence of a fault, properly speaking, crossing the site in bevel in river left. Upon examination of the excavations, only local alterations were observed. The more marked irregularity of the rock roof under the alluvium deviatory behavior. The material is assumed incompressible under creep low. Creep is defined as time-dependent deformation that occurs below the yield strength of a material. The rate of creep deformation is dependent on material behavior (i.e., creep constants), temperature, time, and stress. Classically,

3. MATHEMATICAL CREEP MODELING

While the creep response of materials is intimately related to microstructural processes that take place inside the material during deformation, a continuum description of the creep process has proven to be of great engineering usefulness. Creep, like plasticity, is an irreversible (inelastic) strain, which is based on creep deformation is separated into three distinct stages, primary, secondary, and tertiary creep as depicted in figure 5. Descriptively, these stages are associated with transient, steady-state, and accelerating creep, respectively (Betten, J., 2002).

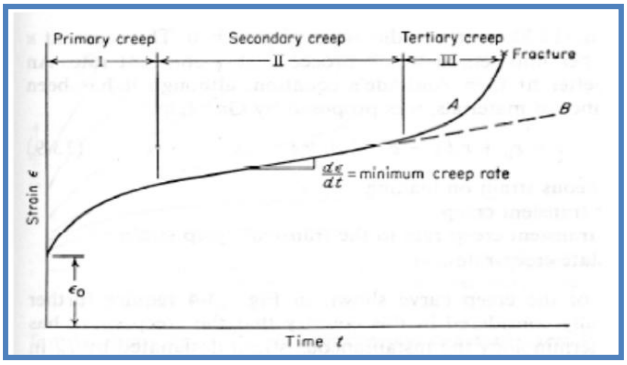


Figure 5. Schematic creep curve (Dieter, G.E, 1988, Ashby, M.F and Jones, 1991)

Linear viscoelastic models considered as physical models are generally composed of one or several elements such as dashpots, springs, or friction elements that represent viscous, elastic, or yielding properties. Kelvin model which is also referred to as Kelvin–Voigt model consists of a linear spring and a dashpot in parallel and is the simplest model that can be used to represent the behavior of a solid polymer component at the beginning of loading. Based on this model (figure 6), the Maxwell model, used for any materials at room temperature, the elastic spring of the Maxwell model represents the elasticity of the material, E_0. The viscoelastic dashpot represents the time dependent strain in the material that is proportional to the stress applied, σ, and inversely proportional to the viscosity of the material, T_0.

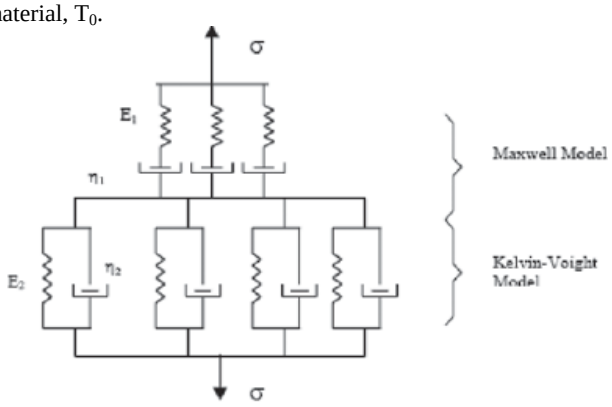


Figure 6. Maxwell and Kelvin Voight Models (Ghouilem, and all, 2013)

This viscoelastic "dashpot" response is represented by σ/T. The Maxwell model shows the elastic spring and viscoelastic dashpot in series; hence, under load equal stresses occur simultaneously. This model represents both creep and stress relaxation responses of a material within its elastic range. The Kelvin-Voight model responds differently than the Maxwell model. Instead of equal stress in the elastic spring and viscous dashpot, this model represents the stress within the material to be a combination of both the elastic spring and dashpot. If the load is applied, the spring only stretches if the time-dependent viscous dashpot has sufficient time to deform. Conversely, when the load is removed, the deformation that has accumulated

in the elastic spring will continue to work toward deforming the viscoelastic dashpot.

a. Primary Creep Modelling

Traditionally, the transient creep observed in the primary creep stage is accounted for using Andrade's law for primary creep of the form (Eq.2):

$$\varepsilon_{cr} = \varepsilon_0 + At^{1/q} \quad (2)$$

Where $\varepsilon_0$is instantaneous creep, A ($t^{-1/q}$) is a coefficient, and q is a unitless exponent. The constant q has been experimentally observed to be 3 for most materials (Andrade, EN. 1910, Dvorkin, J. and al 1994). A number of authors have attempted to disprove the uniformity of this constant with limited success (Nabarro, FRN. 1997). A more advantageous formulation for primary creep is based around a power law of the simple form (Eq.3):

$$\varepsilon_{cr} = A\sigma^n t^m \quad (3)$$

Where

- σ (MPa) is the applied stress
- A ($MPa^{-n}hr^{-m}$), n, and m are temperature-dependent primary creep constants (Pantelakis, S. 1983). When stress is assumed to be constant, a primary creep time-hardening strain rate equation can be developed of the form (Eq.4):

$$\dot{\varepsilon}_{cr} = Am\sigma^n t^{m-1} \quad (4)$$

b. Secondary Creep Modelling

The classical approach to modeling the secondary creep behavior for materials is the Norton power law (Eq.5) for secondary creep (Norton, F.H. (1929):

$$\dot{\varepsilon}_{cr} = A\sigma_{eq}^n \quad (5)$$

Where:
A and n are the secondary creep constants, σeq is an equivalent stress.
Ansys softwar APDL offers a multitude formulation of secondary creep such as:

- Generalized Garofalo (Secandary stage):

$$\dot{\varepsilon}_{cr} = \{C_1\sigma^{C_2}[(C_3+1)\varepsilon_{cr}]^{C_3}\}^{1/(C_3+1)}e^{(-C_4/T)} \quad (6)$$

4. ANSYS CREEP MODELING AND ANALYSIS

ANSYS is able to analyse first and second stages of creep. ANSYS uses Implicit and Explicit methods for creep. Implicit is fast and accurate and works with temperature dependent creep constant. In Divertor analysis, all the material properties are temperature dependent. Explicit method is used for the analyses if it would not allow use to temperature - dependent materials. It does not perform elastic-plastic analysis.

Libraries of creep strain rate equations are included under the "Implicit Creep Equations" and "Explicit Creep Equations" sections of ANSYS 14.0 (ANSYS Element Reference) wich offers us 13 equations creep models. The implicit method is robust, fast, accurate, and recommended for general use, especially with problems involving large creep strain and large deformation. Implicit creep refers to the use of backward Euler integration for creep strain. This means that it does not require as small a time – step as the explicit creep method, so it is much faster overall. It has provisions for including temperature-dependent constants. The program can model pure creep, creep with isotropic hardening plasticity, and creep with kinematic hardening plasticity, using both von Mises and Hill potentials. Since the creep and plasticity are modelled simultaneously (no superposition), the implicit method is more accurate and efficient than the explicit method. Temperature dependency can also be incorporated by the Arrhenius function (see the Mechanical APDL Theory Reference for details).

Element types supported for implicit creep material are:

- PLANE42, SOLID45, PLANE82, SOLID92 and SOLID95
- 18 x families of elements: LINK180, SHELL181, PLANE182, PLANE183, SOLID185, SOLID186, SOLID187, BEAM188 and BEAM189.

The explicit method is useful for cases involving very small time steps, such as in transient analyses. There are no provisions for temperature-dependent constants or simultaneous modelling of creep with any other material models such as plasticity. However, there is temperature dependency using the Arrhenius function, and you can combine explicit creep with other plasticity options using non-simultaneous modelling (superposition). In these cases, the program first performs the plastic analysis, then the creep calculation.

a. Structure discretization

The Finite Element Method (FEM) analysis is a powerful computational technique for approximate solutions. ANSYS is engineering software, worldwide used by researchers for simulation. It develops general purpose of finite element analysis. To create the finite element model in ANSYS there are multiple tasks that have to be completed for the model to run properly. Figure 8, illustrate the dam's discretisation model, the number of elements is approximately 1119 rectangular elements with eight nodes (PLANE183) which is solid with 8 nodes show in (figure 7 below.). Eight nodes having two degrees of freedom at each node define the 8-node element: translations in the nodal x and y directions. The element may be used as a plane element or as an axisymmetric element. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities. Various printout options are also available.

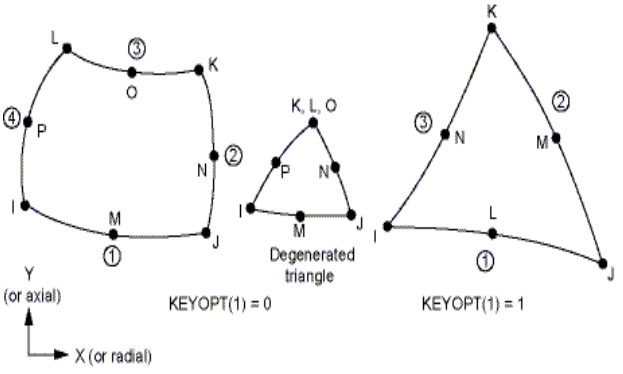


Figure 7. PLANE183 Geometry (ANSYS Element Reference)

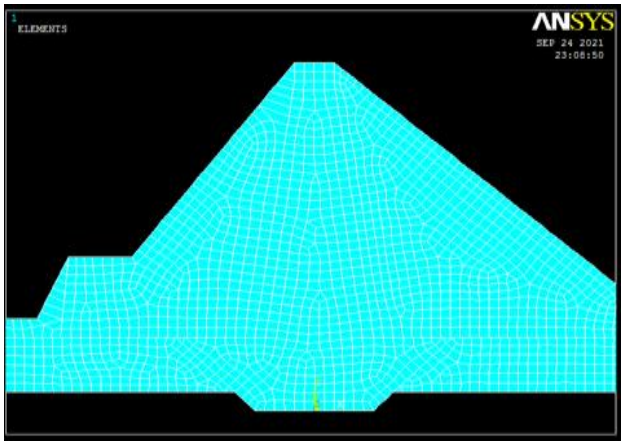


Figure 8. Structure discretization by Element 183

Models can be created using command prompt line input or the Graphical User Interface (GUI).

- The first step is to model the finite element structure by choosing an appropriate item to the type of analysis to be performed. As part of this work, we limited ourselves to address the problem in two-dimensional finite element see figure 8 above.
- The 2nd step is divided into three, namely:

1. Step pre-processor: who is to introduce the geometry of the problem, material properties and Boundary conditions.
2. While in the solution phase, we choose the type of analysis that must be performed.
3. Finally, the results of the completed solution are observed in the post-processing step.

In order to modelling the creep behavior, we have introduced the model equation called (Strain Hardening model) (Eq.8). It is considered that the material is isotropic, and the basic solution method used is that of Newton-Raphson.

$$\dot{\varepsilon}_{cr} = C_1 \sigma^{C_2} t^{C_3} e^{(-C_4/T)} \qquad (8)$$

where:

$\dot{\varepsilon}_{cr}$: Rate Creep strain
σ : Equivalent stress
t: Time at end of sub – steps)
C_1, C_2, C_3, C_4 : Creep clay parameters : $C_1 = 41.10^{-8}$ 1/s, $C_2 = 1.48$, $C_3 = -0.63$, $C_4 = Q/K = 0$,
T : Temperature (Kelvin)

5. NUMERICAL RESULTS AND DISCUSSION

In order to conduct time-dependent numerical modeling, the finite element code ANSYS occurs the different results shown in the following figures. This Item illustrate a time-dependent behavior of clay cores subjected to a constant hydrostatic load, during 20000 hours. Figure 9 and Figure 10 bellow represents the numerical contour plot results of elastic strain (ε_X^{el}) and (ε_Y^{el}) respectivly.

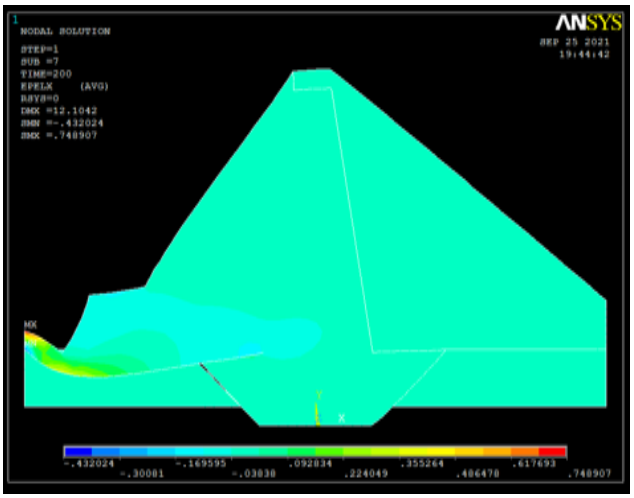


Figure 9. Contour plot of elastic strain $\boldsymbol{\varepsilon_x^{el}}$

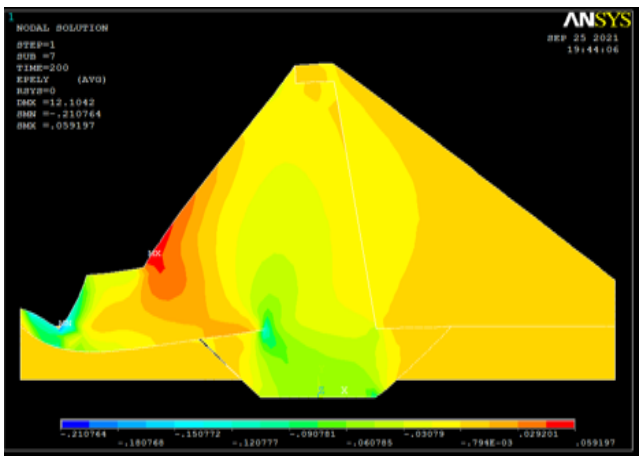


Figure 10. Contour plot of elastic strain $\boldsymbol{\varepsilon_y^{el}}$

Figures 11 and 12, illustrates the contour plot elastic shear stress (τ_{XY}^{el}) and Shear Creep strain (ε_{XY}^{cr}) in the dam structure including the clay core. We note that the clay core and structure dam resist better to shear stresses.

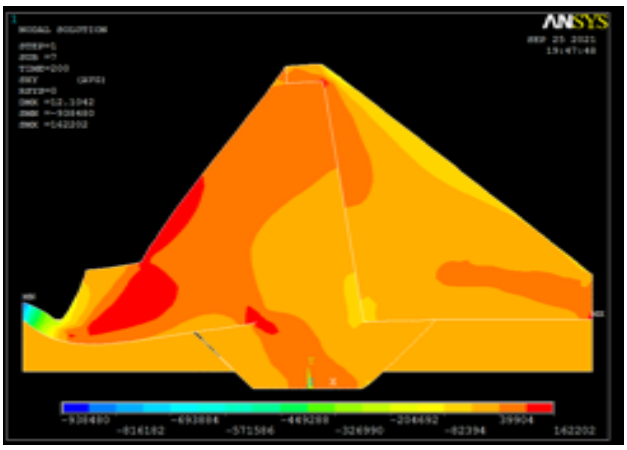


Figure 11. Contour plot of elastic shear stress (τ_{XY}^{el})

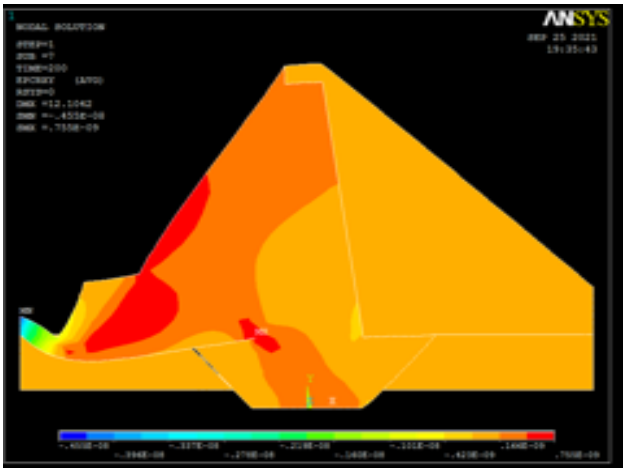


Figure 12. Contour plot shear creep strain (ε_{XY}^{cr})

2. In the clay core material we can note two phase:

- In the 1st phase spread out over an time interval (0< t < 20days) we note an instantaneous elastic strain followed by primary creep with increasing creep strain corresponding to the elastic phase what explains why the material resists the requests better. It corresponds at the beginning of granular rearrangement. In this phase the effect of an increased confining pressure is to decrease creep rate, because confinement acts to suppress the tension stresses. Creep strain thus decreases with increase in confining pressure.
- In the second phase spread out over an time interval (20 days < t < 2000 days), we can note that the creep strains ($\dot{\varepsilon}_X^{cr}$) increase an exponential curve strain with constant creep rate, it actually corresponds to the beginning of the consolidation process of the material. Creep rate thus decreases with increase in confining pressure.

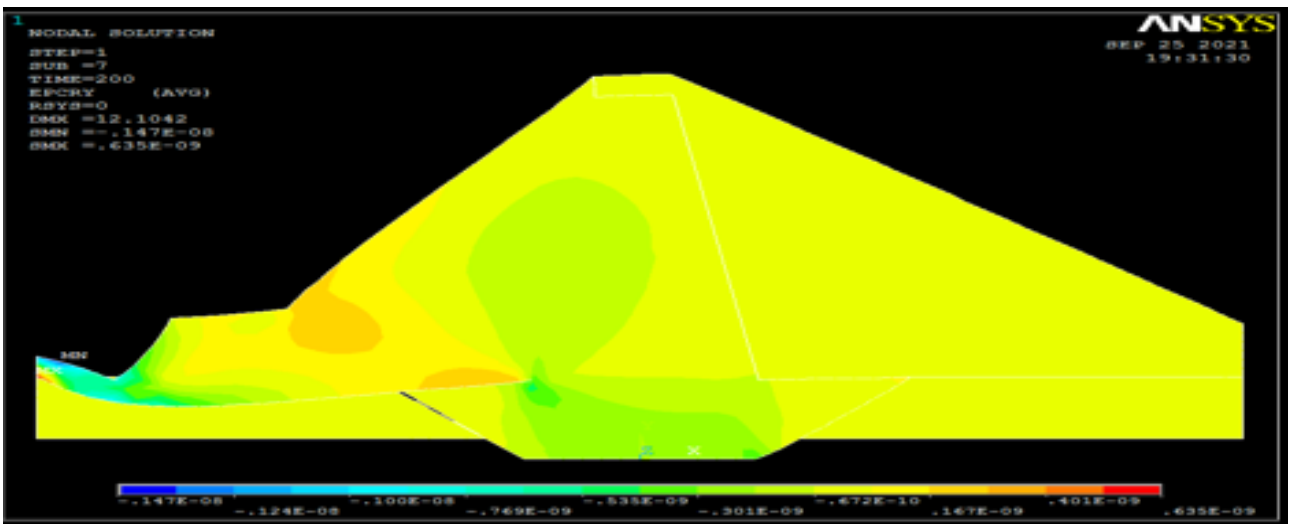


Figure 13. Contour plot of Creep behavior ($\dot{\varepsilon}_y^{cr}$)

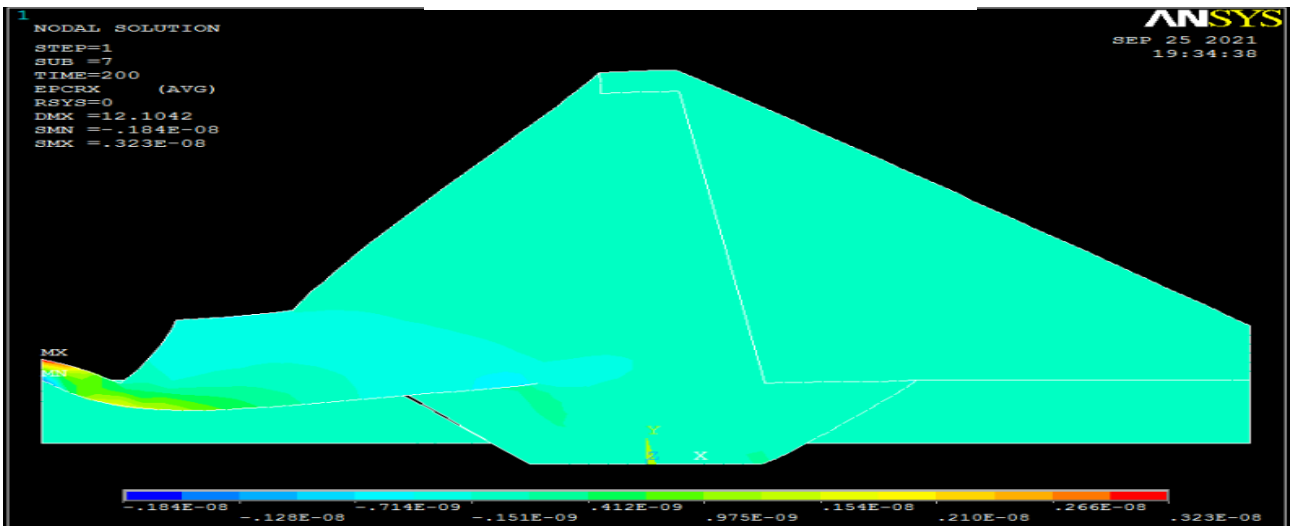


Figure 14. Contour plot of Creep behavior ($\dot{\varepsilon}_X^{cr}$)

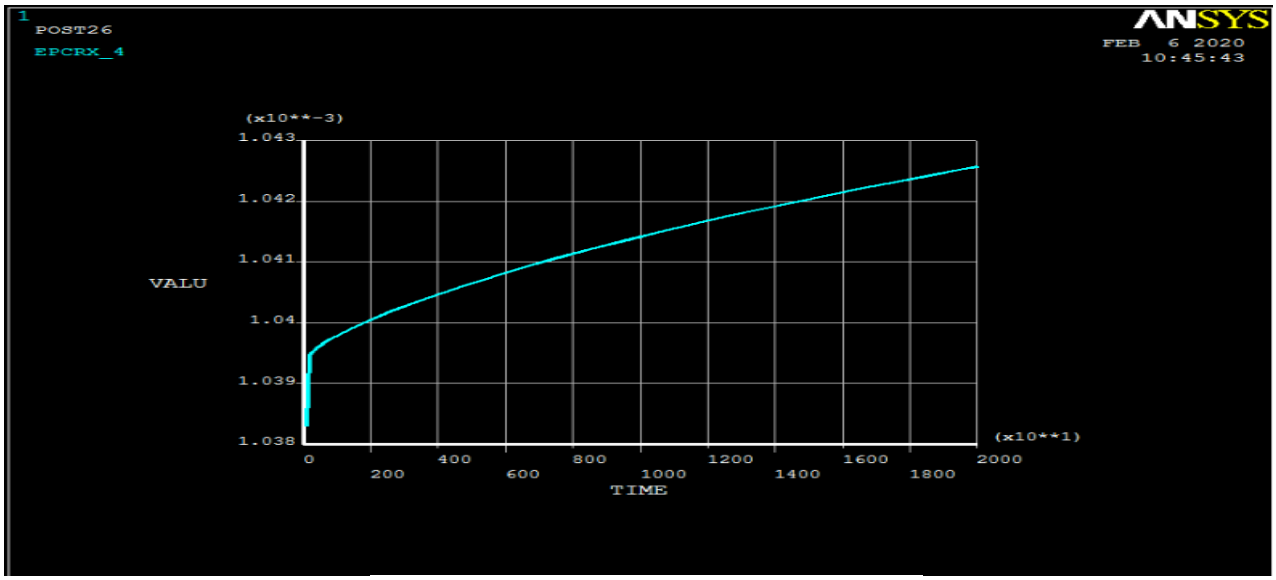


Figure 15. Creep strain curve in the core clay ($\dot{\varepsilon}_X^{cr}$)

However, figure 16, bellow, illustrate that the creep strain ($\dot{\varepsilon}_y^{cr}$) decrease and stabilize for a value of 3.0178 10^{-4}. This phase correspond to secondary creep stage. We note that the creep results curve illustrate in this figure correspond to the results experimental test obtained by (Erol, Orhan 1977) (see figure 1 above).

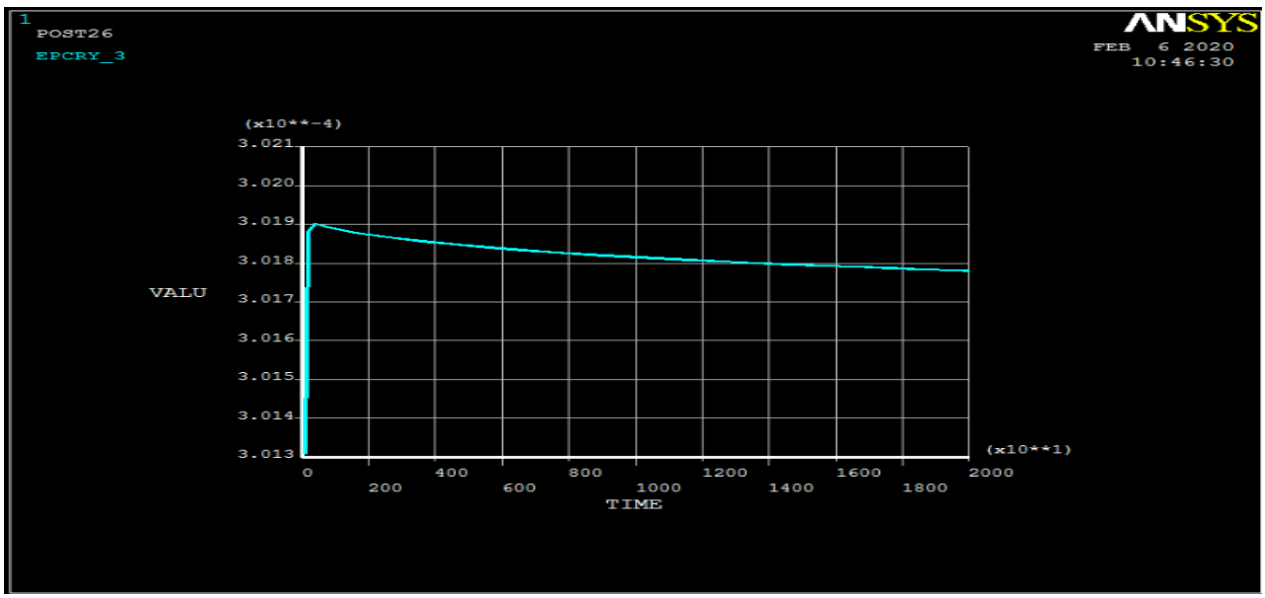


Figure 16. Creep strain curve in the core clay ($\dot{\varepsilon}_y^{cr}$)

6. CONCLUSION

This study contains an outline of the existing literatures concerning creep model and researches of time- dependent behavior in clay materials.

At the macroscopic level, creep (or secondary compression) is defined and characterized in laboratory experiments and in-situ observations.

The different creep equation is presented. Creep is due to the characteristics skeletal viscous and model extrapolation its behavior during the primary phase consolidation.

The domain of validity extends to large amplitude loads, provided that these are applied slowly and following a monotonous growth, as is produced during hydrodynamic consolidation cores clay in dam's structure. The use of the model, as the equation of state of the intergranular skeleton in a one-dimensional consolidation theory, can therefore be considered Based on the numerous experimental studies, and the numerical simulation results of the creep behavior of the clay core in rock fill dams, the following conclusion were drawn:

The creep behavior of clay cores in rock fill dams can provide lasting safety in the operation of dams, thus clay cores constitute a reliable model for the fight against seepage in dams reliable materials

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