Behavior model `BETON_BURGER_FP` for the clean creep of the Summarized

concrete:

This document the model presents clean creep `BETON_BURGER_FP`, which is a way of modelling the clean creep of the concrete. This model is strongly inspired by structure already installation in the model `BETON_UMLV_FP`.

One also details there the writing and the digital processing of the model. The integration of the model (i.e. the update of the stresses) are carried out according to an implicit scheme from the increment of total deflections provided by the total diagram of resolution.

Contents

1 Introduction

Into the frame of the studies of the long-term concrete structure behavior, one dominating share of the strains measured on structure relates to the differed strains which appear in the concrete during its life. They comprise the shrinkages with the young age, the shrinkage of desiccation, clean creep and the creep of desiccation.

The model presented here is dedicated to the modelization of the differed strain associated with clean creep. Clean creep is, in complement of the creep of desiccation, the share of creep of the concrete which one would observe during a test without exchange of water with outside. In experiments the concrete in clean creep presents a growing old viscous behavior. The strain of creep observed is proportional to the stress of loading, depends on the temperature and the hygroscopy.

Models of creep of the existing concretes (e.g.: model of Granger – to see [bib4] and [R7.01.01]) were developed in optics to predict the longitudinal deflections of creep under uniaxial stresses. The generalization of these models, in order to take into account a stress state multiaxial, is done then via a Poisson's ratio of creep arbitrary, constant and equal, or close, elastic Poisson's ratio. However, the determination *a posteriori* of the Poisson's ratio of effective creep shows its dependence with respect to the loading path. In addition, the concrete of certain works of the Park EDF, the such containment systems of nuclear reactor, is subjected in a stress state biaxial. This report led to the clarification of the model of strains of clean creep UMLV (University of Marne-the-Valley, partner in the development of this model) for which the Poisson's ratio of creep is a direct consequence of the computation of the principal strains.
The model `BETON_UMLV_FP` supposes for its in the long run constant part strainrates, rheology which seems not very probable within sight of the experimental results resulting from works of Brooks [bib7]. By preserving structure of model `BETON_UMLV_FP`, one adds nona linearity on the long-term strainrates to correct this point, methodology also employed by Saddler and al. [bib6]. The new developed model is described like phenomenologic

In *Code_Aster*, the model is used under the name of `BETON_BURGER_FP`.

2 Assumptions

Assumption 1 (H.P.P.) The model
is written in the frame of the small disturbances. Assumption

2 (partition of the strains) In small
strains, the tensor of the total deflections is broken up into several terms relating to the processes considered. As regards the description of the various mechanisms of strains differed from the concretes, one admits that the total deflection is written: éq

$$\varepsilon = \underbrace{\varepsilon^{e}}_{\text{déformation élastique}} + \underbrace{\varepsilon^{fp}}_{\text{fluage propre}} + \underbrace{\varepsilon^{fdess}}_{\text{fluage de dessiccation}} + \underbrace{\varepsilon^{\Re}}_{\text{retrait endogène}} + \underbrace{\varepsilon^{rd}}_{\text{retrait de dessiccation}} + \underbrace{\varepsilon^{th}}_{\text{déformation thermique}}$$ 2-1 In

the frame of this documentation, one will be limited to the description of clean creep. A
ends of simplification of writing, the exhibitor F will indicate the clean strain of creep so that [éq 2-1] is reduced to: éq

$$\varepsilon = \varepsilon^{e} + \varepsilon^{f}$$ 2-2 N.B.

: In

the continuation the term “creep” will indicate clean creep exclusively. Assumption

3 (decomposition of the components of creep) In a general

way, clean creep can be modelled by combining the elastic behavior of solid and the viscous behavior of the fluid. For the model presented, creep is described like the combination of the elastic behavior of the hydrates and the aggregates and the viscous behavior of water. In the case of the model BETON _BURGER_FP, one carries out the assumption that creep can be broken up into a process uncoupling a spherical part and a deviatoric part. The tensor of the total deflections of creep is written then: with

$$\underline{\underline{\varepsilon}}^{f}=\underbrace{\varepsilon^{fs}\cdot\underline{\underline{1}}}_{\substack{partie\\ sphérique}}+\underbrace{\underline{\underline{\varepsilon}}^{fd}}_{\substack{partie\\ déviatorique}}$$ éq $\varepsilon^{fs}=\frac{1}{3}\cdot tr\,\underline{\underline{\varepsilon}}^{f}$ the 2-3 tensor

of the stresses can be developed according to a similar form: éq

$$\underline{\underline{\sigma}}=\underbrace{\sigma^{s}\cdot\underline{\underline{1}}}_{\substack{partie\\ sphérique}}+\underbrace{\underline{\underline{\sigma}}^{d}}_{\substack{partie\\ déviatorique}}$$ 2-4 The model

of creep BETON _BURGER_FP supposes a total decoupling between the spherical and deviatoric components: the strains induced by the spherical stresses are purely spherical and the strains induced by the deviatoric stresses are purely deviatoric. On the other hand, the cumulated viscous strains have an effect on the viscous properties of the fluid, some is its source (spherical or deviatoric). To take account of the effect of internal moisture, the strains are multiplied by internal relative moisture: and éq

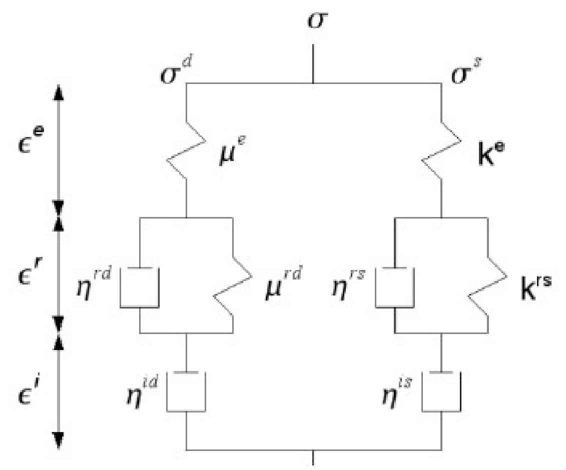
$$\varepsilon^{s}=h\cdot f\left(\sigma^{s}\right) \qquad \underline{\underline{\varepsilon}}^{d}=h\cdot f\left(\underline{\underline{\sigma}}^{d}\right)$$ 2-5 Or

indicates h internal relative moisture. The condition [éq 2-5] makes it possible to check a posteriori that the strains of clean creep are proportional to the relative humidity. Description

3 of the model Figure

to model the clean phenomenon of creep, the model suggested leans on simple rheological models (figure 3-1) 3-1 in series an elastic body (described by behavior ELAS), a solid of linear Voigt Kelvin for the modelization of reversible creep (recouvrance), and a fluid of Maxwell with a nonlinear viscosity to model long-term creep. The character strings spherical and deviatoric are equivalent in their construction. The stage

of Voigt Kelvin has a limit of strain managed by the elasticity modulus (described on figure 4.1 - 4.1-1The characteristic of the model rests on the choice of nonthe linearity assigned to the viscosity of the body of Maxwell (figure 4.2 - 4.2-1



3-1: 3-1 diagram distinguishing the spherical and deviatoric part of the tensor from the stresses

3.1 of the spherical part the spherical

strain of creep is written as the sum of a reversible part and an irreversible part: éq

$$\varepsilon^{fs} = \underbrace{\varepsilon_r^{fs}}_{\substack{partie \\ réversible}} + \underbrace{\varepsilon_i^{fs}}_{\substack{partie \\ irréversible}}$$ the 3.1-1 processes

of strain spherical of creep is controlled by the equations suiivantes (equations [éq 3.1-2] and [éq 3.1-3]): éq

$$h \cdot \sigma^s = k^{rs} \cdot \varepsilon_r^{fs} + \eta^{rs} \cdot \dot{\varepsilon}_r^{fs}$$ 3.1-2 and éq

$$h \cdot \sigma^s = \eta^{is} \cdot \dot{\varepsilon}_i^{fs}$$ 3.1-3 with

: the modulus

- k_r^s of compressibility associated with reversible spherical clean creep, the viscosity
- η_r^s of the stage of Voigt Kelvin associated with reversible spherical clean creep, the nonlinear
- η_i^s spherical viscosity of the fluid of Maxwell. The indicator

associated $\dot{}$ with any variable describes the velocity of evolution of this variable. Description

3.2 of the deviatoric part the deviatoric

strain of creep is also written as the tensorial sum of a reversible part and an irreversible part: éq

$$\underbrace{\underline{\varepsilon}^{fd}}_{\substack{déformation \\ déviatorique \\ totale}} = \underbrace{\underline{\varepsilon}_r^{fd}}_{\substack{contribution \\ réversible}} + \underbrace{\underline{\varepsilon}_i^{fd}}_{\substack{contribution \\ irréversible}}$$ 3.2-1

the principal component jème of the total deviatoric strain is governed by the equations [éq 3.2 - 2] and [éq 3.2 - 3]: éq

$$\eta_r^d \cdot \dot{\varepsilon}_r^{fd,j} + k_r^d \cdot \varepsilon_r^{fd,j} = h \cdot \sigma^{d,j}$$ 3.2-2 and éq

$$\eta_i^d \cdot \dot{\varepsilon}_i^{fd,j} = h \cdot \sigma^{d,j}$$ 3.2-3 with

: the shear modulus

- k_r^d associated with clean creep deviatoric reversible, the viscosity
- η_r^d of the stage of Voigt Kelvin associated with clean creep deviatoric reversible, the nonlinear
  - η_i^d deviatoric viscosity of the fluid of Maxwell. Description

3.3 of non the viscous linearity It not

linearity of viscosity is interpreted according to [bib6] like result of a spherical consolidation of the sample ([bib7]) and of a tangle or blocking of displacements of the averages HSC, components of the mortar. A coefficient of "consolidation" is thus introduced according to the same idea to control the evolution of viscosities. This additional coefficient intervenes on the laws of evolutions of the bodies of Maxwell (spherical and deviatoric). It depends directly on the norm of the tensor of the cumulated irreversible differed strains . This extension of the assumptions posed by [bib6] allows a taking into account of nonthe linearity for any type of ways (with or without spherical loading). The explicit formulation of the bodies of Maxwell is the following one: and

$$\eta_i^s = \eta_{i,0}^s \cdot \exp\left(\frac{\|\varepsilon_m^{fi}\|}{\kappa}\right) \text{ éq } \eta_i^d = \eta_{i,0}^d \cdot \exp\left(\frac{\|\varepsilon_m^{fi}\|}{\kappa}\right)$$ 3.3-1 with

: the initial

- $\eta_{i,0}^s$ viscosity of the fluid of bearing Maxwell on the spherical part initial
- $\eta_{i,0}^d$ viscosity of the fluid of bearing Maxwell on the deviatoric part strain
  - κ characteristic related to an amplified viscosity of a factor exp (1).
  - $\|\varepsilon_m^{fi}\|$ The irreversible equivalent strain, i.e. normalizes it complete tensor (spherical and deviatoric) of strains of irreversible creep, maximum value attack during the loading. The construction

of formula $\|\varepsilon_m^{fi}\|$ following logic: . Restriction $\|\varepsilon_m^{fi}\| = max\left(\|\varepsilon_m^{fi}\|, \sqrt{\underline{\underline{\varepsilon}}^{fi} : \underline{\underline{\varepsilon}}^{fi}}\right)$

3.4 amongst parameters of the model the equivalence

of the rheological character strings deviatoric and spherical makes it possible to obtain, by respecting the following statement [éq 3.4-1], an apparent Poisson's ratio of constant creep: éq.

$$\frac{\eta_{i,0}^s}{\eta_{i,0}^d} = \frac{\eta_r^s}{\eta_r^d} = \frac{k_r^s}{k_r^d} = \frac{(1+\nu)}{(1-2\cdot\nu)} = \beta$$ 3.4-1 For

the use of model BETON `_BURGER_FP on` uniaxial tests of creep, one seldom has the radial strains of the samples making difficult the identification of all the parameters of the model. A first approximation consists in assuming the relation [éq. 3.4-1] and limit thus the number of parameters to be determined to 4. Discretization

4 of the constitutive equations of the model the discretization

employed is similar for the parts spherical and deviatoric in the processing of the strains of reversible creep (identical to the approach employed on reversible creep deviatoric for the model BETON_UMLV_FP [R7.01 .06]). This approach is made possible by the common choice of a character string of Burger to represent the strains spherical and deviatoric. Nonthe linearity introduced on the bodies of Maxwell does not make it possible thereafter any more to follow the same diagram of integration. An implicit approach via a diagram of local Newton will be set up to solve all the equations. The first

assumption consists in linearizing with the first order produces it stresses () and $\underline{\underline{\sigma}}$ relative humidity () on h the temporal interval of resolution: éq $[t_n, t_{n+1}]$

$$\underline{\underline{\sigma}}(t)\cdot h(t)\approx\underline{\underline{\sigma}}_n\cdot h_n+\frac{t-t_n}{\Delta t_n}\left(\Delta\underline{\underline{\sigma}}_n\cdot h_n+\underline{\underline{\sigma}}_n\cdot\Delta h_n\right)$$ 4.1 with

, and $\Delta t_n=t_{n+1}-t_n$ $\Delta\underline{\underline{\sigma}}_n=\underline{\underline{\sigma}}_{n+1}-\underline{\underline{\sigma}}_n$. $\Delta h_n=h_{n+1}-h_n$

The indices related to the stresses and the relative humidity follow the following writing rule:. Discretization $h_n=h_{t_n}$

4.1 of the equations of reversible creep Figure

left spherical and deviatoric are not related any more to the following equations, but the approach is identical. The statement

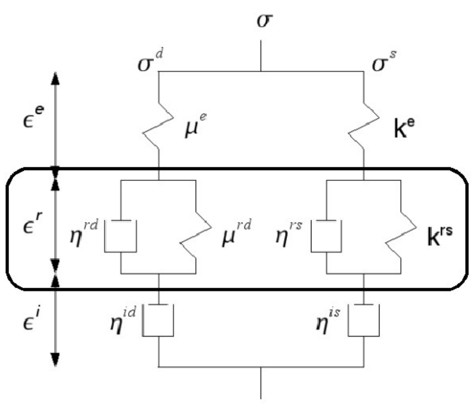
of the stage of Voigt Kelvin takes the following shape, where tensorial viscoelasticity treats in a way similar to elasticity [bib8]: éq

$$\eta_r\cdot\dot{\varepsilon}_r^f(t)+k_r\cdot\varepsilon_r^f(t)=h(t)\cdot\sigma(t)$$ 4.1-1

with

: viscosity

- η_r connecting the stresses at the reversible strainrates, the stiffness $\dot{\varepsilon}_r^f(t)$
- k_r connected to the recoverable deformations humidity $\varepsilon_r^f(t)$
- $h(t)$ relative of the medium the stress state
- $\sigma(t)$ to time. After t



4.1 - 4.1-1 Voigt Kelvin of model BETON _BURGER_FPLes distinctions

being itself assured the strict positivity of the parameters and η_r , one k_r can solve the following homogeneous differential equation: éq

$$\eta_r\cdot\dot{\varepsilon}_r^f(t)+k_r\cdot\varepsilon_r^f(t)=0$$ 4.1-2 the homogeneous

solution is form: The particular $\varepsilon_r^{fh}(t)=\alpha_r\cdot\exp(-k_r/\eta_r\cdot t)$
solution of the differential equation of order 1 presented above takes the following shape: . $\varepsilon_r^{fp}(t)=\beta_r+\gamma_r\cdot(t-t_n)$ The final

statement of the strains of reversible creep arises as follows: The statement

$$\varepsilon_r^f(t)=\varepsilon_r^{fh}(t)+\varepsilon_r^{fp}(t)=\alpha_r\cdot\exp(-k_r/\eta_r\cdot t)+\beta_r+\gamma_r\cdot(t-t_n)$$

of the parameters, and α_r β_r is γ_r the following one: éq.

$$\begin{cases}\alpha_r &= \exp(-k_r/\eta_r\cdot t_n)\cdot(\varepsilon_{r,n}-\beta_r)\\ \beta &= \dfrac{1}{k_r}\cdot\left[\sigma_n\cdot h_n-\dfrac{\eta_r}{k_r}\cdot\left(\dfrac{\Delta\sigma_n\cdot h_n+\sigma_n\cdot\Delta h_n}{\Delta t_n}\right)\right]\\ \gamma_r &= \dfrac{1}{k_r}\cdot\left[\dfrac{\Delta\sigma_n\cdot h_n+\sigma_n\cdot\Delta h_n}{\Delta t_n}\right]\end{cases}$$ 4.1-3 It is

now possible to express the variation of the strain of clean creep reversible in the form: éq.

$$\Delta\underline{\underline{\varepsilon}}_r^f=\underline{\underline{a}}_n^{fr}+b_n^{fr}\cdot\underline{\underline{\sigma}}_n+c_n^{fr}\cdot\underline{\underline{\sigma}}_{n+1}$$ 4.1-4

the statements expected from, and $\underline{\underline{a}}_n^{fr}$ b_n^{fr} are c_n^{fr} the following ones and referred as being [éq. 4.1-3]: Discretization

$$\begin{cases}\underline{\underline{a}}_n^{fr} &= (\exp(-k_r/\eta_r\cdot\Delta t_n)-1)\cdot\underline{\underline{\varepsilon}}_{r,n}^f\\ b_n^{fr} &= \dfrac{1}{k_r}\cdot\left[\left(-\left(\dfrac{2\cdot\eta_r}{k_r\Delta t_n}+1\right)\cdot h_n+\dfrac{\eta_r}{k_r\cdot\Delta t_n}\cdot h_{n+1}\right)\cdot\exp\left(-\dfrac{k_r\Delta t_n}{\eta_r}\right)+\left(\left(\dfrac{2\cdot\eta_r}{k_r\Delta t_n}-1\right)h_n-\dfrac{\eta_r\cdot h_{n+1}}{k_r\cdot\Delta t_n}+h_{n+1}\right)\right]\\ c_n^{fr} &= \dfrac{h_n}{k_r}\left(\dfrac{\eta_r}{k_r\Delta t_n}\cdot\exp\left(-\dfrac{k_r\Delta t_n}{\eta_r}\right)-\dfrac{\eta_r}{k_r\Delta t_n}+1\right)\end{cases}$$

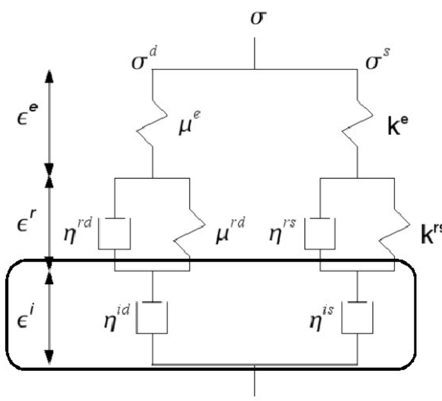
4.2 of the equations of irreversible creep Figure

of the strains resulting from the nonlinear bodies of Maxwell is described thereafter in tensorial form. This change is due to the use of the norm of the tensor of the unrecoverable deformations of clean creep. This quantity controls to it not linearity introduced into the definition of the body of Maxwell [éq. 3.3-1]. During

the integration of these equations, a linear evolution of the strains on the time interval is considered. That is to say the directional $\underline{\underline{n}}$ tensor of the increment of strains defined such as: éq.

$$\dot{\underline{\underline{\varepsilon}}}_i^f(t)=\underline{\underline{n}}\cdot\frac{d\|\underline{\underline{\varepsilon}}_i^f\|}{dt}$$ 4.2-1 From

[éq. 3.3-1], one can then write the following development: éq.



4.2 - 4.2-1 of Maxwell of model BETON `_BURGER_FPL' statement`

$$\underline{\underline{\eta}}_i : \frac{\underline{n}\cdot d\left\|\underline{\varepsilon}_i^f\right\|}{dt} = h_n\cdot\underline{\sigma}_n + \frac{t-t_n}{\Delta t_n}\cdot\left(\Delta\,\underline{\sigma}_n\cdot h_n + \underline{\sigma}_n\cdot\Delta\,h_n\right)$$ 4.2-2 with

. One $\underline{\underline{\eta}}_i = \underline{\underline{\eta}}_{i,0}\cdot\exp\left(\frac{\left\|\varepsilon_m^{fi}\right\|}{\kappa}\right)$ can

then carry out the integration of the terms of left and right-hand side of the preceding equality according to two approaches. The first considers that the loading applied during this interval led to a local discharge. The solution of this equation is then presented to equation 4.2-6. The second way of integration of irreversible creep sees an evolution of the term formulates $\left\|\varepsilon_m^{fi}\right\|$ the imposed loading: Then

$$\underline{\underline{\eta}}_{i,0} : \underline{n}\int_{\left\|\underline{\varepsilon}_{i,n}^f\right\|}^{\left\|\underline{\varepsilon}_{i,n+1}^f\right\|}\exp\left(\frac{\left\|\underline{\varepsilon}_i^f\right\|}{\kappa}\right)\mathrm{d}\left\|\underline{\varepsilon}_i^f\right\| = \int_{t_n}^{t_{n+1}}\left(h_n\cdot\underline{\sigma}_n + \frac{t-t_n}{\Delta t_n}\cdot\left(\Delta\,\underline{\sigma}_n\cdot h_n + \underline{\sigma}_n\cdot\Delta\,h_n\right)\right)\mathrm{d}\,t$$

$$\underline{\underline{\eta}}_{i,0} : \underline{n}\left[\kappa\cdot\exp\left(\frac{\left\|\underline{\varepsilon}_i^f\right\|}{\kappa}\right)\right]_{\left\|\underline{\varepsilon}_{i,n}^f\right\|}^{\left\|\underline{\varepsilon}_{i,n+1}^f\right\|} = \left[\left(h_n\cdot\underline{\sigma}_n\cdot t + \frac{\left(t-t_n\right)^2}{2\cdot\Delta t_n}\cdot\left(\Delta\,\underline{\sigma}_n\cdot h_n + \underline{\sigma}_n\cdot\Delta\,h_n\right)\right)\right]_{t_n}^{t_{n+1}}$$

$$\kappa\,\underline{\underline{\eta}}_{i,0} : \underline{n}\left[\exp\left(\frac{\left\|\underline{\varepsilon}_{i,n+1}^f\right\|}{\kappa}\right) - \exp\left(\frac{\left\|\underline{\varepsilon}_{i,n}^f\right\|}{\kappa}\right)\right] = \Delta t_n\cdot\left[h_n\cdot\underline{\sigma}_n + \frac{1}{2}\cdot\left(\Delta\,\underline{\sigma}_n\cdot h_n + \underline{\sigma}_n\cdot\Delta\,h_n\right)\right]$$

, éq.

$$\kappa\,\underline{\underline{\eta}}_{i,0} : \underline{n}\left[\exp\left(\frac{\left\|\underline{\varepsilon}_{i,n+1}^f\right\|}{\kappa}\right) - \exp\left(\frac{\left\|\underline{\varepsilon}_{i,n}^f\right\|}{\kappa}\right)\right] = \frac{\Delta t_n}{2}\cdot\left[h_n\cdot\underline{\sigma}_{n+1} + h_{n+1}\cdot\underline{\sigma}_n\right]$$ 4.2-3 the relation

éq.4.2-3 will be part of the system of equations nonlinear to solve by the local method of Newton. Thereafter

, by means of the relation, one $\Delta\,\underline{\varepsilon}_i^f = \Delta\left\|\underline{\varepsilon}_i^f\right\|\cdot\underline{n}$ obtains the following statement: éq .

$$\Delta\,\underline{\varepsilon}_{i,n}^f = \frac{\Delta\left\|\underline{\varepsilon}_{i,n}^f\right\|\cdot\Delta t_n\cdot\left[h_n\cdot\underline{\sigma}_{n+1} + h_{n+1}\cdot\underline{\sigma}_n\right]}{2\cdot\kappa\,\underline{\underline{\eta}}_{i,0}\cdot\left[\exp\left(\frac{\left\|\underline{\varepsilon}_{i,n+1}^f\right\|}{\kappa}\right) - \exp\left(\frac{\left\|\underline{\varepsilon}_{i,n}^f\right\|}{\kappa}\right)\right]}$$ 4.2-4 the writing

of this relation in the form is $\Delta\,\underline{\varepsilon}_i^f = \underline{a}_n^{fi} + b_n^{fi}\cdot\underline{\sigma}_n + c_n^{fi}\cdot\underline{\sigma}_{n+1}$ possible. The tensorial term is $\underline{a}_n^{fi}$ null and the statement of and b_n^{fi} contains c_n^{fi} the value, quantity $\left\|\underline{\varepsilon}_{i,n+1}^f\right\|$ only known after the local integration of the model: éq .

$$\begin{cases} b_n^{fi} = \dfrac{(\eta_{i,0})^{-1}\cdot\Delta\|\underline{\underline{\varepsilon}}_{i,n}^f\|\cdot\Delta t_n\cdot h_{n+1}}{2\cdot\kappa\cdot\left[\exp\left(\dfrac{\|\underline{\underline{\varepsilon}}_{i,n+1}^f\|}{\kappa}\right)-\exp\left(\dfrac{\|\underline{\underline{\varepsilon}}_{i,n}^f\|}{\kappa}\right)\right]} \\ c_n^{fi} = \dfrac{(\eta_{i,0})^{-1}\cdot\Delta\|\underline{\underline{\varepsilon}}_{i,n}^f\|\cdot\Delta t_n\cdot h_n}{2\cdot\kappa\cdot\left[\exp\left(\dfrac{\|\underline{\underline{\varepsilon}}_{i,n+1}^f\|}{\kappa}\right)-\exp\left(\dfrac{\|\underline{\underline{\varepsilon}}_{i,n}^f\|}{\kappa}\right)\right]} \end{cases}$$

4.2-5 the term

appears $\eta_{i,0}$ in the form of a scalar, because after partly spherical and deviatoric decomposition of the stress tensors and strains, the term of viscosity is reduced to this statement. The form presented above is generic and does not distinguish the two parts. The statement

of the nonlinear body of Maxwell does not make it possible to obtain a relation of the type, with $\Delta\underline{\varepsilon}_i^f=\underline{a}_n^{fi}+b_n^{fi}\cdot\underline{\sigma}_n+c_n^{fi}\cdot\underline{\sigma}_{n+1}$, and $\underline{a}_n^{fi}$ b_n^{fi} built c_n^{fi} only from quantities defined in time. This t_n aspect modifies considerably the diagram of integration of the model in comparison with the approach established for the model BETON_UMLV_FP [R7.01 .06]. Consequently, the integration of the model in this form results in considering the resolution of a system of equations nonlinear by the method of Newton (§ 5). 12
To simplify and find an approach similar to model BETON_UMLV_FP , one can linearize with the 1st order around their initial position the terms into exponential. Under these assumptions, the evaluating of the irreversible strains of creep following a formula of the type is $\Delta\underline{\varepsilon}_i^f=\underline{a}_n^{fi}+b_n^{fi}\cdot\underline{\sigma}_n+c_n^{fi}\cdot\underline{\sigma}_{n+1}$ possible. The equation to be considered becomes then: éq.

$$\underline{\underline{\eta}}_{i,0}:\Delta\underline{\underline{\varepsilon}}_{i,n}^f=\exp\left(\frac{-\|\underline{\underline{\varepsilon}}_{i,n}^f\|}{\kappa}\right)\cdot\frac{\Delta t_n}{2}\cdot\left[h_n\cdot\underline{\sigma}_{n+1}+h_{n+1}\cdot\underline{\sigma}_n\right]$$

4.2-6 the statement

of the terms, and $\underline{a}_n^{fi}$ b_n^{fi} is c_n^{fi} generic and must be declined with the parts spherical and deviatoric of the strain tensors and stresses. In this form, tensorial viscosity treats in a way similar to elasticity [bib8]: éq.

$$\begin{cases} \underline{\underline{a}}_n^{fi} = 0 \\ b_n^{fi} = \dfrac{(\eta_{i,0})^{-1}\cdot\Delta t_n\cdot h_{n+1}}{2\cdot\exp\left(\|\underline{\underline{\varepsilon}}_{i,n}^f\|/\kappa\right)} \\ c_n^{fi} = \dfrac{(\eta_{i,0})^{-1}\cdot\Delta t_n\cdot h_n}{2\cdot\exp\left(\|\underline{\underline{\varepsilon}}_{i,n}^f\|/\kappa\right)} \end{cases}$$

4.2-7 This

linearization of the equations will be used as predictor of Eulerian for the method of local resolution of Newton . Discretization

4.3 of the equations of the creep of desiccation

the terms related to the taking into account of the creep of desiccation break up according to the same concept as the terms of reversible clean creep [bib3]: éq.

$$\Delta\underline{\varepsilon}^{fdess}=\underline{a}_n^{fdess}+b_n^{fdess}\cdot\underline{\sigma}_n+c_n^{fdess}\cdot\underline{\sigma}_{n+1}$$

4.3-1 the statement

of the various terms is the following one: éq.

$$\begin{cases} \underline{\underline{a}}_n^{fdess} = 0 \\ b_n^{fdess} = \dfrac{\Delta h_n}{2 \cdot \eta^{fd}} \\ c_n^{fdess} = \dfrac{\Delta h_n}{2 \cdot \eta^{fd}} \end{cases}$$ 4.3-2 general

5 Outline of local integration the diagram

of local integration selected for the model installation of BETON _BURGER_FP entirely implicit and is formulated on the incremental problem. It uses an elastic prediction then iterations of correction, if necessary. The purpose of it is producing, an increment of strains $\Delta \underline{\varepsilon}$ being provided, the value of the stresses and local variables at time. Code t_{n+1}
- Aster currently does not propose integration clarifies for this model. Phase

5.1 of prediction the "

elastic" phase of prediction is based on the approach used by the diagram employed for the model BETON_UMLV_FP . Indeed, the prediction is established from the linearization with the 1st order of the unrecoverable terms of deformations [éq 4.2-7]. The algorithm is based on the capacity to break up the stages of Voigt Kelvin and nonlinear bodies of Maxwell in the form, where $\Delta \underline{\varepsilon}^f = \underline{a}_n^f + b_n^f \cdot \underline{\sigma}_n + c_n^f \cdot \underline{\sigma}_{n+1}$ the terms, and $\underline{a}_n^f$ b_n^f depend c_n^f only on quantities defined in time. t_n The evaluating of the stress states $\underline{\sigma}_{n+1}$ is obtained by the following relation: éq.

$$\underline{\sigma}_{n+1} = \frac{\left[\underline{\underline{E}}(t_{n+1}) : \left(\underline{\underline{E}}(t_n)\right)^{-1} : \underline{\sigma}_n\right] + \underline{\underline{E}}(t_{n+1}) : \left[\Delta \underline{\varepsilon} - \underline{a}_n - \underline{\underline{b}}_n : \underline{\sigma}_n\right]}{\underline{\underline{1}} + \underline{\underline{E}}(t_{n+1}) : \underline{\underline{c}}_n}$$ 5.1-1 the value

obtained of the stresses then makes it possible to define a first estimate for the strains of clean creep and desiccation. The norm
of the difference between the terms of left and right-hand side of the equation [éq. 4.2-3] is tested compared to a value of convergence specified by user [RESI_INTE_RELA] . If this difference is lower than the value expected by the user, one restricts oneself with this evaluating. In the contrary case, the process of "plastic" phase of correction is committed. Just
as specified above, if the loading does not lead an increase in formula $\left\|\varepsilon_m^{fi}\right\|$ the predictor obtained (éq. 5.1-1) is the solution exact of the equation to be solved. Phase

5.2 of correction

the nonlinear unknowns of the system of equations are the stresses, and the $\underline{\sigma}_{n+1}$ total unrecoverable deformations (spherical $\underline{\varepsilon}_{n+1}^{fi}$ and deviatoric). The vector of the unknowns thus comprises to the maximum for modelizations 3D 12 unknowns (6 per tensor).
The nonlinear equations to solve are the following ones: Decomposition
◦ of the total deflections (6 scalar equations) (E1): éq.5

$$\Delta \underline{\varepsilon} - \left(\underline{\underline{E}}(t_{n+1})\right)^{-1} : \underline{\sigma}_{n+1} + \left(\underline{\underline{E}}(t_n)\right)^{-1} : \underline{\sigma}_n - \Delta \underline{\varepsilon}^{fr}(\underline{\sigma}_n, \underline{\sigma}_{n+1}) - \Delta \underline{\varepsilon}^{fi} - \Delta \underline{\varepsilon}^{fdess}(\underline{\sigma}_n, \underline{\sigma}_{n+1}) = \underline{0}$$ .2-1 Bodies

◦ of nonlinear Maxwell (6 scalar equations) (E2): éq.5

$$\kappa \underline{\underline{\eta}}_{i,0} : \underline{n} \left[\exp\left(\frac{\left\|\underline{\varepsilon}_{n+1}^{fi}\right\|}{\kappa}\right) - \exp\left(\frac{\left\|\varepsilon_{m,n}^{fi}\right\|}{\kappa}\right)\right] - \frac{\Delta t}{2} \cdot \left[h_n \cdot \underline{\sigma}_{n+1} + h_{n+1} \cdot \underline{\sigma}_n\right] = \underline{0}$$ .2-2 These

equations constitute a square system, where $R(\Delta Y)$ the unknowns are. With $\Delta Y = \left(\Delta \underline{\sigma}, \Delta \underline{\varepsilon}^{fi}\right)$ the iteration of j the loop of on-the-spot correction of Newton, one solves the following matric equation: éq.

$$\frac{dR(\Delta Y^j)}{d\,\Delta Y^j}\cdot\delta(\Delta Y^{j+1})=-R(\Delta Y^j)$$ 5.2-3 the jacobian matrix

, asymmetric $\frac{dR(\Delta Y^j)}{d\,\Delta Y^j}$, is built in the following way: , that is to say

$$\frac{dR(\Delta Y^j)}{d\,\Delta Y^j}=\begin{bmatrix}\frac{\partial E1}{\partial\sigma_{n+1}^{j}} & \frac{\partial E1}{\partial\varepsilon_{n+1}^{fi,j}}\\ \frac{\partial E2}{\partial\sigma_{n+1}^{j}} & \frac{\partial E2}{\partial\varepsilon_{n+1}^{fi,j}}\end{bmatrix}\text{ with }\frac{dR(\Delta Y^j)}{d\,\Delta Y^j}=\begin{bmatrix}-\left[\left(\underline{\underline{E}}(t_{n+1})\right)^{-1}+\underline{\underline{c}}_n^{fr}+\underline{\underline{c}}_n^{fdess}\right] & -\underline{\underline{1}}\\ \frac{-\Delta t}{2}\cdot h_n\cdot\underline{\underline{1}} & \frac{\partial E2}{\partial\varepsilon_{n+1}^{fi,j}}\end{bmatrix}$$

: With

$$\frac{\partial E2}{\partial\varepsilon_{n+1}^{fi,j}}=\kappa\cdot\underline{\underline{\eta}}_{i,0}:\left[\frac{\underline{\underline{n}}}{\kappa}\otimes\frac{\underline{\underline{\varepsilon}}_{n+1}^{fi,j}}{\left\|\underline{\underline{\varepsilon}}_{n+1}^{fi,j}\right\|}\cdot\exp\left(\frac{\left\|\underline{\underline{\varepsilon}}_{n+1}^{fi,j}\right\|}{\kappa}\right)+\left(\exp\left(\frac{\left\|\underline{\underline{\varepsilon}}_{n+1}^{fi,j}\right\|}{\kappa}\right)-\exp\left(\frac{\left\|\varepsilon_{m,n}^{fi}\right\|}{\kappa}\right)\right)\cdot\frac{\left\|\Delta\underline{\underline{\varepsilon}}_n^{fi}\right\|-\Delta\underline{\underline{\varepsilon}}_n^{fi}\otimes\frac{\Delta\underline{\underline{\varepsilon}}_n^{fi}}{\left\|\Delta\underline{\underline{\varepsilon}}_n^{fi}\right\|}}{\left\|\Delta\underline{\underline{\varepsilon}}_n^{fi}\right\|^2}\right]$$

an aim of standardizing the scales between the various equations to be solved, one makes the choice to put at the level of strains bearing the E2 equation on the strains of irreversible clean creep. One applies for that the reverse of coefficient ETA_IS () material parameter $\eta_{i,0}^{s}$. This choice makes it possible to ensure a more uniform convergence on the group of the system. Convergence

famous is acquired since. Phase $\left\|R(\Delta Y^{j+1})\right\|<$ RESI_INTE_RELA

5.3 of update the update

of the vector solution is carried out according to the following operation: éq .

$$\Delta Y=\Delta Y^{j+1}=\Delta Y^j+\delta\Delta Y^{j+1}$$ 5.3-1 This

phase of update consists in deferring the evolution of the stresses, reversible, irreversible strains of creep and of desiccation. Tangent

6 operator consisting the tangent

operator can be obtained directly starting from the preceding system of equations nonlinear. Indeed, the formed system by the equations of the model with convergence is checked at the end of the increment. For a small variation of, by R regarding this time the increase in total deflection $\Delta\varepsilon_n$ variable and not as parameter, the system remains with the equilibrium and one checks, i.e. $dR=0$: éq .

$$\frac{\partial R}{\partial \underline{\sigma}}\delta\underline{\sigma}+\frac{\partial R}{\partial \Delta\underline{\underline{\varepsilon}}_n}\delta\Delta\underline{\underline{\varepsilon}}_n+\frac{\partial R}{\partial \underline{\underline{\varepsilon}}_i^f}\delta\underline{\underline{\varepsilon}}_i^f=0$$ 6-1 This system

can be still written: , with

$$\frac{\partial R}{\partial Y}\delta Y=X \text{ and } Y=\begin{bmatrix}\sigma\\ \varepsilon_i^f\end{bmatrix} \text{ éq. } X=\begin{bmatrix}\delta\Delta\varepsilon_n\\ 0\end{bmatrix}$$ 6-2 By writing

the jacobian matrix in the form: éq.

$$J\cdot\delta Y=\begin{bmatrix}Y_0 & Y_1\\ Y_2 & Y_3\end{bmatrix}\cdot\begin{bmatrix}\delta\sigma\\ \delta\varepsilon_i^f\end{bmatrix}$$ 6-3 While operating

by successive eliminations and substitutions, the required tangent operator can be written directly: éq.

$$\left[\frac{\delta\Delta\sigma}{\delta\Delta\varepsilon}\right]_n=\left[Y_0-Y_1\cdot\left(Y_3\right)^{-1}Y_2\right]^{-1}$$ 6-4 Description

7 of the local variables the following

table gives the correspondence between the number of the local variables accessible by Code_Aster *and their* description: Number

of the variable reversible	**Description 1**
	spherical Strain 2 irreversible
	spherical Strain 3 reversible
	deviatoric Strain, component 11 4 irreversible
	deviatoric Strain, component 11 5 reversible
	deviatoric Strain, component 22 6 irreversible
	deviatoric Strain, component 22 7 reversible
	deviatoric Strain, component 33 8 irreversible
	deviatoric Strain, component 33 9 Creep
	of desiccation , component 11 10 Creep
	of desiccation , component 22 11 Creep
	of desiccation , component 33 12 reversible
	deviatoric Strain, component 12 13 irreversible
	deviatoric Strain, component 12 14 reversible
	deviatoric Strain, component 13 15 irreversible
	deviatoric Strain, component 13 16 reversible
	deviatoric Strain, component 23 17 irreversible
	deviatoric Strain, component 23 18 Creep
	of desiccation , component 12 19 Creep
	of desiccation , component 13 20 Creep
	of desiccation , component 23 21 irreversible
21	equivalent Strain maximum Notations

8 tensor

$\underline{\underline{\varepsilon}}$ of the total deflections tensor

$\underline{\underline{\varepsilon}}^f$ of the strains of tensor clean creep

$\underline{\underline{\varepsilon}}^e$ of the elastic strain left

$\varepsilon^{fs}\underline{\underline{1}}$ spherical the tensor of the strains of clean creep left

$\varepsilon_r^{fs}\underline{\underline{1}}$ spherical reversible the tensor of the strains of clean creep left

$\varepsilon_i^{fs}\underline{\underline{1}}$ spherical irreversible the tensor of the strains of clean creep left

$\underline{\underline{\varepsilon}}^{fd}$ deviatoric the tensor of the strains of clean creep left

$\underline{\underline{\varepsilon}}_r^{fd}$ deviatoric reversible the tensor of the strains of clean creep left

$\underline{\underline{\varepsilon}}_i^{fd}$ deviatoric irreversible the tensor of the strains of complete tensor clean

$\underline{\underline{\varepsilon}}^{fi}$ creep of the strains of tensor irreversible creep

$\underline{\underline{\varepsilon}}^{fdess}$ of the strains of tensor creep of desiccation

$\underline{\underline{\sigma}}$ of the total stresses left

$\sigma^s \underline{\underline{1}}$ spherical the tensor of the stresses deviatoric

$\underline{\underline{\sigma}}^d$ part of the tensor of the stresses relative

h humidity interns stiffness

k_r^s connect associated with the spherical Voigt Kelvin stiffness

k_r^d connect associated with the Voigt Kelvin deviatoric viscosity

η_i^s connect associated with the spherical unrecoverable deformations viscosity

η_r^s connect associated with the spherical Voigt Kelvin viscosity

η_i^d connect associated with the deviatoric unrecoverable deformations viscosity

η_r^d associated with the Voigt Kelvin deviatoric indicate

$x, \underline{x}, \underline{\underline{x}}$ a scalar respectively, a vector and a tensor of order 2. respectively

$x_n, x_{n+1}, \Delta x_n$ indicate the value of quantity X at *time* , t_n the time and t_{n+1} the variation of during

x the interval. Bibliography $[t_n ; t_{n+1}]$

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10 and checking This document

relates to constitutive law BETON_BURGER _FP (key word COMP_INCR of STAT_NON_LINE) and its associated material BETON_BURGER _FP (command DEFI_MATERIAU). This constitutive law

is checked by the cases following tests: SSNV163 clean

Computation	of creep [V6.04.163	] SSNV174 Taken
into	account of the shrinkage in models BETON_UMLV_FP and BETON_ BURGER _FP [V6.04.174	] SSNV180 Taken
into	account of thermal thermal expansion and the creep of desiccation in models BETON_UMLV_FP and BETON _BURGER _FP [V6.04.180	] SSNV181 Checking
	of the good taking into account of the shears in models BETON_UMLV_FP and BETON _BURGER _FP [V6.04.181	] COMP003 Test
of behaviors	specific to the concretes. Simulation in a material point thermomechanical	V6.07.103 COMP011
	Validation of the models for the concrete V6.07.111	Description

11 of the versions of the document Version Aster

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	EDF/R & D /AMA initial Text	