Behavior model BETON_UMLV_FP for the clean creep of the Summarized

concrete:

This document the model presents clean creep UMLV (behavior BETON_UMLV_FP), which is a way of modelling the clean creep of the concrete.

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 incremental diagram from the increment of total deflections provided by the total diagram of resolution.

One adds the description of the coupling between clean creep and the model of MAZARS. The integration of the model (i.e. the update of the stresses) are carried out according to a "total" diagram starting from the total deflections cumulated since the initial state before loading.

Contents

1 Introduction

Into the frame as of studies of the long-term concrete structure behavior, a 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.

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

2 Assumptions

Assumption 1 (H.P.P.) The model
is written in the frame as of 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 concrete, one admits that the total deflection is written: éq

$$\varepsilon = \underbrace{\varepsilon^{e}}_{\substack{\text{déformation}\\ \text{élastique}}} + \underbrace{\varepsilon^{fp}}_{\substack{\text{fluage}\\ \text{propre}}} + \underbrace{\varepsilon^{fd}}_{\substack{\text{fluage de}\\ \text{dessiccation}}} + \underbrace{\varepsilon^{\Re}}_{\substack{\text{retrait}\\ \text{endogène}}} + \underbrace{\varepsilon^{rd}}_{\substack{\text{retrait de}\\ \text{dessiccation}}} + \underbrace{\varepsilon^{th}}_{\substack{\text{déformation}\\ \text{thermique}}}$$ 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 model UMLV, 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

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

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

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

UMLV 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. To take account of the effect of internal moisture, the stresses 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 [bib1] Description

3.1 of the spherical part

the spherical stresses are at the origin of the migration of the water adsorbed with the interfaces between the hydrates on the level of the macroporosity and absorptive within microporosity in capillary porosity. The diffusion of water interlamellaire of the pores of hydrates towards capillary porosity is carried out in an irreversible way. The total spherical strain of creep is thus 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 following system of equations coupled (equations [éq 3.1-2] and [éq 3.1-3]): éq

$$\dot{\varepsilon}^{fs}=\frac{1}{\eta_r^s}\cdot\left[h\cdot\sigma^s-k_r^s\cdot\varepsilon_r^{fs}\right]-\dot{\varepsilon}_i^{fs}$$

3.1-2 where

indicates k_r^s the stiffness connects associated with the squelette formed by blocks with hydrates on a mesoscopic scale; and

viscosity η_r^s connects associated with the mechanism with diffusion within capillary porosity. éq

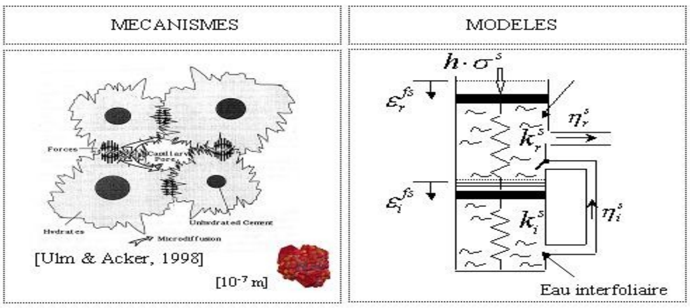
$$\dot{\varepsilon}_i^{fs}=\frac{1}{\eta_i^s}\left\langle\left[k_r^s\cdot\varepsilon^{fs}-\left(k_r^s+k_i^s\right)\cdot\varepsilon_i^{fs}\right]-\left[h\sigma^s-k_r^s\cdot\varepsilon_r^{fs}\right]\right\rangle^+$$

3.1-3 where

indicates k_i^s the stiffness connects intrinsically associated with the hydrates on a microscopic scale; and

viscosity η_i^s connects associated with the interfoliaceous mechanism of diffusion. In

[éq 3.1-3], the hooks appoint $\langle\rangle^+$ the operator of Mac Cauley: Figure $\langle x\rangle^+=\frac{1}{2}\left(x+|x|\right)$



3.1 - phenomenologic Model a: associated with the spherical part of clean creep Description

3.2 of the deviatoric part

the deviatoric stresses are at the origin of a mechanism of sliding (or mechanism of quasi dislocation) of the averages of HSC in nano-porosity. Under deviatoric stress, creep is carried out with constant volume. In addition, creep model UMLV supposes the deviatoric isotropy of creep. Phénoménologiquement, the mechanism of sliding comprises a viscoelastic reversible contribution of water strongly adsorbed to the averages of HSC and a viscous irreversible contribution of free water: éq

$$\underbrace{\underline{\varepsilon}^{fd}}_{\substack{\text{déformation}\\ \text{déviatorique}\\ \text{totale}}} = \underbrace{\underline{\varepsilon}_r^{fd}}_{\substack{\text{contribution}\\ \text{eau}\\ \text{absobée}}} + \underbrace{\underline{\varepsilon}_i^{fd}}_{\substack{\text{contribution}\\ \text{eau}\\ \text{libre}}}$$

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

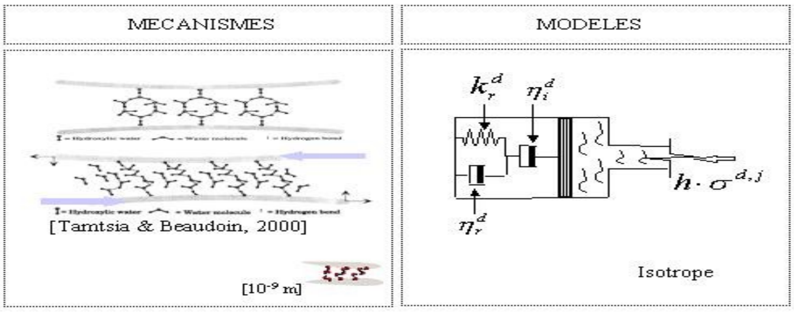
$$\eta_r^d \dot{\varepsilon}_r^{d,j} + k_r^d \varepsilon_r^{d,j} = h \cdot \sigma^{d,j}$$ 3.2-2 where

indicates k_r^d the stiffness associated with the capacity with water adsorbed to transmit loads (load **bearing toilets);** and

viscosity η_r^d associated with the water adsorbed by the averages with hydrates. éq

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

η_i^d the viscosity of free water indicates. Figure



3.2 - phenomenologic Model a: associated with the deviatoric part of clean creep Discretization

4 of the constitutive equations of the model Discretization

4.1 of the constitutive equations of spherical creep One carries out

a linearization with the first order of the product of the stresses and moisture: éq

$$\sigma(t) \cdot h(t) \approx \sigma_n \cdot h_n + \frac{t - t_n}{\Delta t_n} \left(\Delta \sigma_n \cdot h_n + \sigma_n \cdot \Delta h_n \right)$$ 4.1-1 After

discretization of the stresses and the relative humidity by functions closely connected, the spherical strain of clean creep is discretized by the following equation: éq

$$\Delta \varepsilon_n^{fs} = a_n^s + b_n^s \cdot \sigma_n^s + c_n^s \cdot \sigma_{n+1}^s \Leftrightarrow \Delta \left(tr \ \underline{\underline{\varepsilon}}^f \right) = 3 a_n^s + b_n^s \cdot tr \ \underline{\underline{\sigma}}_n + c_n^s \cdot tr \ \underline{\underline{\sigma}}_{n+1}$$ 4.1-2 where

and σ_n^s is σ_{n+1}^s the spherical stresses at the beginning and time step running. Two cases should be distinguished according to whether the unrecoverable deformation must be taken into account or not. 1st

case : the strain of spherical creep irreversible is not taken into account, the equation [éq 4.1 - 2] can be put in the form (simple character string of Kelvin): éq

$$\eta_r^s \dot{\varepsilon}_r^{fs}(t) + k_r^s \varepsilon_r^{fs}(t) = h(t) \sigma_r^s(t)$$ 4.1-3 After

discretization, the preceding equation can be put in the form: éq

$$\Delta\varepsilon_{r,n}^{fs}=a_{r,n}^{s}+b_{r,n}^{s}\cdot\sigma_{n}^{s}+c_{r,n}^{s}\cdot\sigma_{n+1}^{s}$$ 4.1-4 With

: éq

$$\begin{cases} a_{r,n}^{s}=\left[\exp\left(-\frac{\Delta t_n}{\tau_r^s}\right)-1\right]\cdot\varepsilon_{r,n}^{fs} \\ b_{r,n}^{s}=\frac{1}{k_r^s}\left\{\left[-\left(\frac{2\tau_r^s}{\Delta t_n}+1\right)h_n+\frac{\tau_r^s}{\Delta t_n}h_{n+1}\right]\exp\left(-\frac{\Delta t_n}{\tau_r^s}\right)+\left[\left(\frac{2\tau_r^s}{\Delta t_n}-1\right)h_n-\frac{\tau_r^s-\Delta t_n}{\Delta t_n}h_{n+1}\right]\right\} \\ c_{r,n}^{s}=\frac{1}{k_r^s}\left[\frac{\tau_r^s}{\Delta t_n}\exp\left(-\frac{\Delta t_n}{\tau_r^s}\right)h_n-\frac{\tau_r^s-\Delta t_n}{\Delta t_n}h_n\right] \end{cases}$$ 4.1-5 the

unrecoverable

deformation, as for it, does not vary: éq

$$\Delta\varepsilon_{i,n}^{fs}=0\Rightarrow\begin{cases} a_{i,n}^{s}=0 \\ b_{i,n}^{s}=0 \\ c_{i,n}^{s}=0 \end{cases}$$ 4.1-6 2nd

case : the strain of spherical creep irreversible must be taken into account. Using the linearization [éq 4.1-1],], the system of equations coupled is written: éq

$$\begin{cases} \dot{\varepsilon}_r^{fs}(t)+2\dot{\varepsilon}_i^{fs}(t)=\frac{1}{\eta_r^s}\left[\sigma_n\cdot h_n+\frac{t-t_n}{\Delta t_n}\left(\Delta\sigma_n\cdot h_n+\sigma_n\cdot\Delta h_n\right)-k_r^s\varepsilon_r^{fs}(t)\right] \\ \dot{\varepsilon}_i^{fs}(t)=-\frac{1}{\eta_i^s}\left(-2\mathrm{k}_r^s\varepsilon_r^{fs}(t)+k_i^s\varepsilon_i^{fs}(t)+\sigma_n\cdot h_n+\frac{t-t_n}{\Delta t_n}\left(\Delta\sigma_n\cdot h_n+\sigma_n\cdot\Delta h_n\right)\right) \end{cases}$$ 4.1-7 This system

can be put in the form: éq

$$\underline{\dot{\varepsilon}}^{fs}(t)=\begin{bmatrix}\dot{\varepsilon}_r^{fs}(t)\\ \dot{\varepsilon}_i^{fs}(t)\end{bmatrix}=\underline{\underline{A}}:\underline{\varepsilon}_r^{fs}(t)+\underline{b}+\left(t-t_n\right)\underline{c}\Leftrightarrow\begin{cases}\dot{\varepsilon}_r^{fs}(t)=a_{rr}^s\varepsilon_r^{fs}(t)+a_{ri}^s\varepsilon_i^s(t)+b_r^s+c_r^s\left(t-t_n\right)\\ \dot{\varepsilon}_i^{fs}(t)=a_{ir}^s\varepsilon_r^{fs}(t)+a_{ii}^s\varepsilon_i^s(t)+b_i^s+c_i^s\left(t-t_n\right)\end{cases}$$ **4.1-8, and**

$\underline{\underline{A}}$ $\underline{b}$ is $\underline{c}$ defined as follows: éq

$$\underline{\underline{A}}=\begin{bmatrix} a_{rr}^s & a_{ri}^s \\ a_{ir}^s & a_{ii}^s \end{bmatrix} = \begin{bmatrix} -\frac{k_r^s}{\eta_r^s}-4\frac{k_r^s}{\eta_i^s} & 2\frac{k_i^s}{\eta_i^s} \\ 2\frac{k_r^s}{\eta_i^s} & -\frac{k_i^s}{\eta_i^s} \end{bmatrix}$$

$$\underline{b}=\begin{bmatrix} b_r^s \\ b_i^s \end{bmatrix} = \sigma_n \cdot h_n \begin{bmatrix} \frac{1}{\eta_r^s}+\frac{2}{\eta_i^s} \\ -\frac{1}{\eta_i^s} \end{bmatrix}$$ 4.1-9 the

$$\underline{c}=\begin{bmatrix} c_r^s \\ c_i^s \end{bmatrix} = \frac{\Delta\sigma_n \cdot h_n+\sigma_n \cdot \Delta h_n}{\Delta t_n} \begin{bmatrix} \frac{1}{\eta_r^s}+\frac{2}{\eta_i^s} \\ -\frac{1}{\eta_i^s} \end{bmatrix}$$

preceding

system of equations can be decoupled and solved within the space of eigenvectors. The system of equations is written indeed: éq

$$\dot{\varepsilon}_k^*(t)=\lambda_k\,\varepsilon_k^*(t)+b_k^*+c_k^*\left(t-t_n\right) \text{ avec } \underline{\dot{\varepsilon}}^*=\begin{bmatrix}\dot{\varepsilon}_1^* \\ \dot{\varepsilon}_2^*\end{bmatrix}=\underline{\underline{P}}^{-1}\cdot\underline{\dot{\varepsilon}}$$ 4.1-10 Thus

, within the space of eigenvectors, the model of creep becomes equivalent to a double character string of Kelvin. It is necessary to know the solution of the homogeneous equation (without second member), as well as a particular solution in order to solve the preceding differential equation. The homogeneous solution of each of the two equations is the following one: éq

$$\varepsilon_k^*(t)=\mu_k\,e^{\lambda_k \cdot t}$$ 4.1-11 where

is μ_k a parameter depend on the initial condition. A particular solution is obtained by the method of variation of the constant (). $\mu_k=\mu_k(t$The following solutions then are obtained: éq

$$\varepsilon_k^*(t)=\mu_k\,e^{\lambda_k \cdot t}-\frac{1}{\lambda_k}\left[b_k^*+c_k^*\left(t-t_n+\frac{1}{\lambda_k}\right)\right]$$ the 4.1-12

spherical strains of reversible and irreversible creep are then equal to: éq

$$\begin{cases} \varepsilon_r^{fs}(t_{n+1})=\frac{\sigma_n \cdot \Delta h_n+\sigma_{n+1}\cdot h_n}{k_r^s}+\left(x_1\,\mu_1\,e^{\lambda_1 t_{n+1}}+\mu_2 e^{\lambda_2 t_{n+1}}\right) \\ \varepsilon_i^{fs}(t_{n+1})=\frac{\sigma_n \cdot \Delta h_n+\sigma_{n+1}\cdot h_n}{k_i^s}+\left(\mu_1\,e^{\lambda_1 t_{n+1}}+x_2\,\mu_2 e^{\lambda_2 t_{n+1}}\right) \end{cases}$$ 4.1-13 After

simplification, one then obtains the following statements for the values of: éq μ_k

$$\begin{cases} \mu_1=\dfrac{1}{(x_1\cdot x_2-1)e^{\lambda_1 t_n}}\left[x_2\left(\varepsilon_r^{fs}(t_n)-\dfrac{\sigma_n\cdot\Delta h_n+\sigma_{n+1}\cdot h_n}{k_r^s}\right)-\left(\varepsilon_i^{fs}(t_n)-\dfrac{\sigma_n\cdot\Delta h_n+\sigma_{n+1}\cdot h_n}{k_i^s}\right)\right] \\ \mu_2=\dfrac{1}{(x_1\cdot x_2-1)e^{\lambda_2 t_n}}\left[-\left(\varepsilon_r^{fs}(t_n)-\dfrac{\sigma_n\cdot\Delta h_n+\sigma_{n+1}\cdot h_n}{k_r^s}\right)+x_1\left(\varepsilon_i^{fs}(t_n)-\dfrac{\sigma_n\cdot\Delta h_n+\sigma_{n+1}\cdot h_n}{k_i^s}\right)\right]\end{cases}$$ 4.1-14

the equation [éq 4.1-2] can thus be put in the form, after discretization: éq

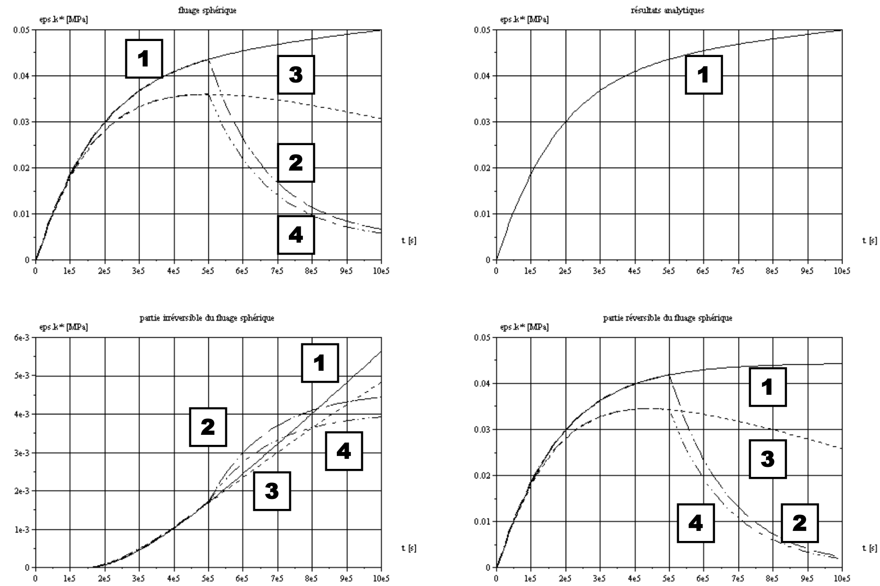
$$\begin{cases}\Delta\varepsilon_{r,n}^{fs}=a_{r,n}^s+b_{r,n}^s\cdot\sigma_n^s+c_{i,n}^s\cdot\sigma_{n+1}^s \\ \Delta\varepsilon_{i,n}^{fs}=a_{i,n}^s+b_{i,n}^s\cdot\sigma_n^s+c_{i,n}^s\cdot\sigma_{n+1}^s\end{cases}$$ 4.1-15 With

: éq

$$\begin{cases} a_{r,n}^s=\left[\dfrac{x_1\cdot x_2\cdot e^{\lambda_1\Delta t_n}-e^{\lambda_2\Delta t_n}}{x_1\cdot x_2-1}-1\right]\cdot\varepsilon_{r,n}^{fs}-x_1\cdot\left[\dfrac{e^{\lambda_1\Delta t_n}-e^{\lambda_2\Delta t_n}}{x_1\cdot x_2-1}\right]\cdot\max_{k\le n}\left(\varepsilon_{i,k}^{fs}\right) \\ b_{r,n}^s=\dfrac{\Delta h_n}{k_r^s}\cdot\left[\dfrac{-x_1\cdot x_2\cdot e^{\lambda_1\Delta t_n}+e^{\lambda_2\Delta t_n}}{x_1\cdot x_2-1}+1\right]+\dfrac{\Delta h_n}{k_i^s}\cdot x_1\cdot\left[\dfrac{e^{\lambda_1\Delta t_n}-e^{\lambda_2\Delta t_n}}{x_1\cdot x_2-1}\right] \\ c_{r,n}^s=\dfrac{h_n}{k_r^s}\cdot\left[\dfrac{-x_1\cdot x_2\cdot e^{\lambda_1\Delta t_n}+e^{\lambda_2\Delta t_n}}{x_1\cdot x_2-1}+1\right]+\dfrac{h_n}{k_i^s}\cdot x_1\cdot\left[\dfrac{e^{\lambda_1\Delta t_n}-e^{\lambda_2\Delta t_n}}{x_1\cdot x_2-1}\right]\end{cases}$$ 4.1-16 éq

$$\begin{cases} a_{i,n}^s=x_2\cdot\left[\dfrac{e^{\lambda_1\Delta t_n}-e^{\lambda_2\Delta t_n}}{x_1\cdot x_2-1}\right]\cdot\varepsilon_{r,n}^{fs}+\left[\dfrac{x_1\cdot x_2\cdot e^{\lambda_2\Delta t_n}-e^{\lambda_1\Delta t_n}}{x_1\cdot x_2-1}-1\right]\cdot\max_{k\le n}\left(\varepsilon_{i,k}^{fs}\right) \\ b_{i,n}^s=\dfrac{\Delta h_n}{k_r^s}\cdot x_2\cdot\left[\dfrac{e^{\lambda_2\Delta t_n}-e^{\lambda_1\Delta t_n}}{x_1\cdot x_2-1}\right]+\dfrac{\Delta h_n}{k_i^s}\cdot\left[\dfrac{-x_1\cdot x_2\cdot e^{\lambda_2\Delta t_n}+e^{\lambda_1\Delta t_n}}{x_1\cdot x_2-1}+1\right] \\ c_{i,n}^s=\dfrac{h_n}{k_r^s}\cdot x_2\cdot\left[\dfrac{e^{\lambda_2\Delta t_n}-e^{\lambda_1\Delta t_n}}{x_1\cdot x_2-1}\right]+\dfrac{h_n}{k_i^s}\cdot\left[\dfrac{-x_1\cdot x_2\cdot e^{\lambda_2\Delta t_n}+e^{\lambda_1\Delta t_n}}{x_1\cdot x_2-1}+1\right]\end{cases}$$ 4.1-17 In

the equations [éq 4.1-16] and [éq 4.1-17] the parameters, λ_1 and λ_2 x are x_2 function of the intrinsic parameters of the material. A each computation step, it is necessary to save two **local variables,** $\varepsilon_{r,n}^{fs}$ the last reversible spherical strain obtained and, i.e. $\max_{k\le n}\left(\varepsilon_{i,k}^{fs}\right)$, $\varepsilon_{i,n}^{fs}$ more the reversible spherical large deformation obtained in the history of the element. The choice to retain the statements [éq 4.1-5] and [éq 4.1-6] (not of unrecoverable deformation), or the statements [éq 4.1 - 16] and [éq 4.1-17] (existence of unrecoverable deformations) to determine the increment of total spherical strain is carried out a posteriori *according to* the sign of in $\Delta\varepsilon_{i,n}^{fs}$ [éq 4.1-15]. Illustration



of the numerical responses obtained by means of discretized statements [éq 4.1-3] with [éq 4.1-17] for four load histories: 1 level of unit stress to constant moisture (100%), 2 level of unit stress to linearly decreasing moisture of 100% to 50%,3 level of unit stress during half of the period of the computation followed by a recouvrance to half of the initial stress on the second part of computation; moisture is supposed to be constant (100%), 4 the mechanical loading is identical to 3; moisture decrease linearly of 100% to 50%. Appear

4.1-a

to carry out simulations of [Figure 4.1-a] the following parameters were retained: [MPa $k_r^s = 2{,}0\text{e}+5$]; [MPa.s] $\eta_r^s = 4{,}0\text{e}+10$; [MPa] $k_i^s = 1{,}0\text{e}+4$; [MPa.s]. The computation $\eta_i^s = 1{,}0\text{e}+11$ comprises 200 intervals of 5000 [S]. Deviatoric

4.2 discretization of the constitutive equations of creep After discretization

of the stresses and the relative humidity by functions closely connected, the deviative tensor of the strains of clean creep is discretized by the following equation: éq 4.2-1

$$\Delta \underline{\varepsilon}_n^{fd} = \underline{a}_n^d + b_n^d \cdot \underline{\sigma}_n^d + c_n^d \cdot \underline{\sigma}_{n+1}^d$$ where and is

$\underline{\sigma}_n^d$ the tensors $\underline{\sigma}_{n+1}^d$ of the deviatoric stresses at the beginning and time step running. The stages
carried out are: One calculates

- the parameters compared to the reversible strain of clean creep deviatoric *, of which the model* is: éq 4.2-2

$$\eta_r^d \dot{\underline{\varepsilon}}_r^{fd}(t) + k_r^d \underline{\varepsilon}_r^{fd}(t) = h(t)\underline{\sigma}^d(t)$$ After discretization

, the preceding equation can be put in the form: éq 4.2-3

$$\Delta \underline{\underline{\varepsilon}}^{fd}_{r,n} = \underline{\underline{a}}^{d}_{r,n} + b^{d}_{r,n} \cdot \underline{\underline{\sigma}}^{d}_{n} + c^{d}_{r,n} \cdot \underline{\underline{\sigma}}^{d}_{n+1}$$

With: éq

4.2-4

$$\begin{cases} \underline{\underline{a}}^{d}_{r,n} = \left[\exp\left(-\dfrac{\Delta t_n}{\tau^d_r} \right) - 1 \right] \cdot \underline{\underline{\varepsilon}}^{f,d}_{r,n} \\ b^{d}_{r,n} = \dfrac{1}{k^d_r} \left\{ \left[-\left(\dfrac{2\tau^d_r}{\Delta t_n} + 1 \right) h_n + \dfrac{\tau^d_r}{\Delta t_n} h_{n+1} \right] \exp\left(-\dfrac{\Delta t_n}{\tau^d_r} \right) + \left[\left(\dfrac{2\tau^d_r}{\Delta t_n} - 1 \right) h_n - \dfrac{\tau^d_r - \Delta t_n}{\Delta t_n} h_{n+1} \right] \right\} \\ c^{d}_{r,n} = \dfrac{1}{k^d_r} \left[\dfrac{\tau^d_r}{\Delta t_n} \exp\left(-\dfrac{\Delta t_n}{\tau^d_r} \right) h_n - \dfrac{\tau^d_r - \Delta t_n}{\Delta t_n} h_n \right] \end{cases}$$

Note:

: The equation

[éq 4.2-4] (left reversible creep deviatoric) is similar to the equation [éq 4.1-5] (left reversible creep in the absence of unrecoverable deformations). They correspond to the discretization of a single character string of Kelvin. One calculates

the parameters compared to the strain of clean creep deviatoric, of which the model is: éq 4.2-5

$$\eta^d_i \, \dot{\underline{\underline{\varepsilon}}}^{f,d}_i(t) = h(t) \underline{\underline{\sigma}}^d(t)$$

After discretization

, the preceding equation can be put in the form: éq 4.2-6

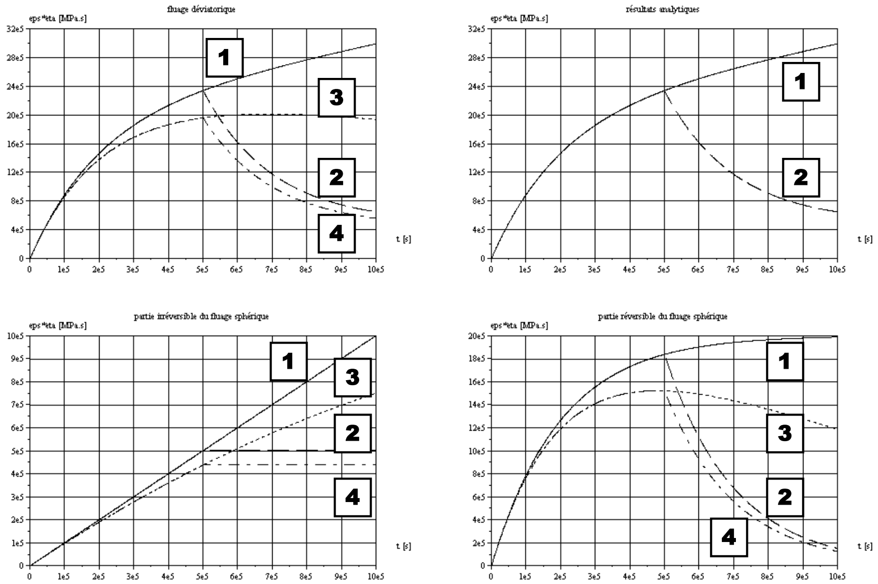
$$\Delta \underline{\underline{\varepsilon}}^{f,d}_{i,n+1} = \underline{\underline{a}}^{d}_{i,n} + b^{d}_{i,n} \cdot \underline{\underline{\sigma}}^{d}_{n} + c^{d}_{i,n} \cdot \underline{\underline{\sigma}}^{d}_{n+1}$$

With: éq

4.2-7

$$\begin{cases} \underline{\underline{a}}^{d}_{i,n} = 0 \\ b^{d}_{r,n} = \dfrac{\Delta t_n \cdot h_{n+1}}{2\eta^d_i} \\ c^{d}_{r,n} = \dfrac{\Delta t_n \cdot h_n}{2\eta^d_i} \end{cases}$$

Illustration



of the numerical responses obtained by means of discretized statements [éq 4.2-1] with [éq 4.2-7] for four load histories: 1 level of unit stress to constant moisture (100%), 2 level of unit stress to linearly decreasing moisture of 100% to 50%,3 level of unit stress during half of the period of the computation followed by a recouvrance to half of the initial stress on the second part of computation; moisture is supposed to be constant (100%), 4 the mechanical loading is identical to 3; moisture varies linearly decreasing from 100% to 50%. Figure 4.2

- has to carry out

simulations of [Figure 4.2-a], the following parameters were retained: [MPa]; $k_r^d = 5{,}0\mathrm{e}{+}4$ [MPa.s]; [$\eta_r^d = 1{,}0\mathrm{e}{+}10$ MPa.s]. The computation $\eta_i^d = 1{,}0\mathrm{e}{+}11$ comprises 1000 intervals of 1000 [S]. Stamp tangent

5 By introducing

the elastic shear modulus, the deviator μ of the stresses at time is written according to $n+1$ the deviator of the elastic strain: éq 5-1 In substituent

$$\underline{\sigma}_{n+1}^{d} = 2\mu\,\underline{\varepsilon}_{n+1}^{ed} = \underline{\sigma}_{n}^{d} + 2\mu\Delta\,\underline{\varepsilon}_{n}^{d} - 2\mu\Delta\,\underline{\varepsilon}_{n}^{f,d}$$

the deviatoric part of the clean strain of creep by the statement [éq 4.2-1], it rises the following relation: éq 5-2 Statement

$$\underline{\sigma}_{n+1}^{d}\left(1+2\mu c^{d}\right) = \underline{\sigma}_{n}^{d}\left(1-2\mu b^{d}\right) + 2\mu\Delta\,\underline{\varepsilon}_{n}^{d} - 2\mu a^{d}\,\underline{1}$$ which induces

by derivative compared to: éq 5-3 By taking $\underline{\underline{\varepsilon}}_{n+1}^{d}$

$$\frac{\partial \underline{\underline{\sigma}}_{n+1}^{d}}{\partial \underline{\underline{\varepsilon}}_{n+1}^{d}}\left(1+2\mu c^{d}\right)=2\mu\,\underline{\underline{\underline{1}}}$$

a similar step for the spherical part and by introducing the modulus of stiffness to thermal expansion, it follows the three K following relations: éq 5-4 éq 5-5

$$tr\ \underline{\underline{\sigma}}_{n+1}=3\mathrm{K}\ tr\ \underline{\underline{\varepsilon}}_{n+1}^{e}=tr\ \underline{\underline{\sigma}}_{n}+3\mathrm{K}\ tr\left(\Delta\,\underline{\underline{\varepsilon}}_{n}\right)-3\mathrm{K}\ tr\left(\Delta\,\underline{\underline{\varepsilon}}_{n}^{f}\right)$$ éq the 5-6

$$tr\ \underline{\underline{\sigma}}_{n+1}\left(1+3\,Kc^{s}\right)=tr\ \underline{\underline{\sigma}}_{n}\left(1-3\,Kb^{s}\right)+3\mathrm{K}\ tr\left(\Delta\,\underline{\underline{\varepsilon}}_{n}\right)-Ka^{s}$$ tangent

$$\frac{\partial\left(tr\ \underline{\underline{\sigma}}_{n+1}\right)}{\partial\left(tr\ \underline{\underline{\varepsilon}}_{n+1}\right)}\left(1+3\,Kc^{s}\right)=3\mathrm{K}$$ matrix

is written finally: éq 5-7 I.e.

$$\frac{\partial \underline{\underline{\sigma}}}{\partial \underline{\underline{\varepsilon}}}=\frac{\partial \underline{\underline{\sigma}}^{d}}{\partial \underline{\underline{\varepsilon}}}+\frac{1}{3}\frac{\partial\left(tr\ \underline{\underline{\sigma}}\right)}{\partial \underline{\underline{\varepsilon}}}\underline{\underline{1}}=\frac{\partial \underline{\underline{\sigma}}^{d}}{\partial \underline{\underline{\varepsilon}}^{d}}\frac{\partial \underline{\underline{\varepsilon}}^{d}}{\partial \underline{\underline{\varepsilon}}}+\frac{1}{3}\frac{\partial\left(tr\ \underline{\underline{\sigma}}\right)}{\partial\left(tr\ \underline{\underline{\varepsilon}}\right)}\frac{\partial\left(tr\ \underline{\underline{\varepsilon}}\right)}{\partial \underline{\underline{\varepsilon}}}\underline{\underline{1}}$$

: éq 5-8 After linearization

$$\frac{\partial \underline{\underline{\sigma}}}{\partial \underline{\underline{\varepsilon}}}=\frac{2\mu}{\underbrace{1+2\mu c^{d}}_{\chi}}\left(\underline{\underline{\underline{1}}}-\frac{1}{3}\underline{\underline{1}}\otimes\underline{\underline{1}}\right)+\frac{K}{\underbrace{1+3\,Kc^{s}}_{\xi}}\underline{\underline{1}}\otimes\underline{\underline{1}}$$

, the tangent matrix develops as follows: éq 5-9 Coupling

$$\begin{pmatrix}\Delta\sigma_{11}\\ \Delta\sigma_{22}\\ \Delta\sigma_{33}\\ \sqrt{2}\,\Delta\sigma_{12}\\ \sqrt{2}\,\Delta\sigma_{13}\\ \sqrt{2}\,\Delta\sigma_{23}\end{pmatrix}=\begin{bmatrix}\xi+\frac{2}{3}\chi & \xi-\frac{1}{3}\chi & \xi-\frac{1}{3}\chi & 0 & 0 & 0\\ \xi-\frac{1}{3}\chi & \xi+\frac{2}{3}\chi & \xi-\frac{1}{3}\chi & 0 & 0 & 0\\ \xi-\frac{1}{3}\chi & \xi-\frac{1}{3}\chi & \xi+\frac{2}{3}\chi & 0 & 0 & 0\\ 0 & 0 & 0 & \chi & 0 & 0\\ 0 & 0 & 0 & 0 & \chi & 0\\ 0 & 0 & 0 & 0 & 0 & \chi\end{bmatrix}\cdot\begin{pmatrix}\Delta\varepsilon_{11}\\ \Delta\varepsilon_{22}\\ \Delta\varepsilon_{33}\\ \sqrt{2}\,\Delta\varepsilon_{12}\\ \sqrt{2}\,\Delta\varepsilon_{13}\\ \sqrt{2}\,\Delta\varepsilon_{23}\end{pmatrix}$$ between

6 BETON_UMLV_FP and MAZARS The model BETON_UMLV_FP

is a model of viscoelastic behavior linear. To be able to represent the fracture of the concrete by tertiary creep, one proposes in Code_Aster the model to couple creep with a model of damage to knowing the model of MAZARS (cf [R7.01 .08]). The coupling is carried out by supposing on the one hand, that the strains of creep are generated by the effective stresses (either, those really seen by the material) and on the other hand, that only part of the strain of creep (presumedly constant) contributes to the evolution of the damage. The diagram is carried out by maintaining the direct link between strain state elastics and stress state. Implementation for

6.1 a local modelization of the up to date damage Put of

6.1.1 the local variables of creep As for the rest of the page

, one is limited here to the description of the coupling between the damage and clean creep. One thus supposes like previously that the strain is written according to the equation [éq 2-2]: where, elastic strain

$$\varepsilon=\varepsilon^e+\varepsilon^f$$

ε^e , contains also the contribution of the damage (micro - cracking) generated by the model of MAZARS. By making the sum of the equations related on spherical creep [éq 4.1-2] and to creep deviatoric [éq 4.2-1], one obtains the increment of the strains of creep between times $\Delta \underline{\underline{\varepsilon}}^f$ N and n+1. éq *6.1* - 1 *with*

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

the coefficients

$\underline{\underline{a}}_n , b_n c_n$ of total clean creep in linear viscoelasticity. To introduce the damage into the model, it is supposed that strains of creep are generated by the effective stresses, noted in the continuation of $\underline{\underline{\sigma}}'$ the document. That makes it possible to associate the strains differed with the just part of the material, as proposed in [1]. It is pointed out that

the effective stresses can be written according to the variable of damage or (see also D documentation [R7.01.08-B]) like a model of elasticity: éq 6.1-2 Consequently

$$\underline{\underline{\sigma}}'=\frac{\underline{\underline{\sigma}}}{1-D}=\underline{\underline{\underline{\underline{E}}}}\underline{\underline{\varepsilon}}^e$$

,

the equation [éq 6.1-1] becomes: éq 6.1-3 By means of

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

the model of elasticity [éq 6.1-2] with the equation [éq 6.1-3], one obtains the new relation for the increment of strain of creep: éq 6.1-4 Thus,

$$\Delta \underline{\underline{\varepsilon}}_n^f=\left(1+c\underline{\underline{\underline{\underline{E}}}}\right)^{-1}\left[\underline{\underline{a}}_n+b_n \underline{\underline{\sigma}}'_n+c_n \underline{\underline{\underline{\underline{E}}}}\left(\underline{\underline{\varepsilon}}_{n+1}-\underline{\underline{\varepsilon}}_n^f\right)\right]$$

from

all the quantities known at time, it is possible n to calculate with the relation [éq 6.1-4] the strain of creep at time. Then, one easily $n+1$ obtains the effective stresses at time thanks to the relation $n+1$ [éq 6.1-2], and the local variables of creep with the equations [éq 4.1-2] and [éq 4.2-1]. Evolution of

6.1.2 the damage One redétaille

not here the model of MAZARS; the reader will be able to refer to the documentation of reference of Code_Aster of the model of MAZARS [R7.01.08]. The basic assumption
is that the damage is controlled by the elastic strain and a quota of the strain of creep. The strain tensor which controls the evolution of D is given by the following relation: éq 6.2-1 with

$$\breve{\underline{\underline{\varepsilon}}}=\underline{\underline{\varepsilon}}^e+\chi\,\underline{\underline{\varepsilon}}^f$$

, coefficient

of $0\le\chi\le1$ *coupling. The level of coupling*

increases with crescent. There thus χ exist two borderline cases: and. If, there is $\chi=0$ absence of $\chi=1$

- coupling $\chi=0$; the evolution of the damage depends only on the elastic strain and thus one cannot have tertiary creep. If the coupling
- is $\chi=1$ maximum, the damage depends on the total deflection. This case generally leads to the premature failure of structure. By means of let us notice that

L "equation [éq 6.2-1] is equivalent to realize the total and elastic deflections, the coefficient like weight: éq χ 6.2-2a or

$$\breve{\underline{\underline{\varepsilon}}}=\chi\,\underline{\underline{\varepsilon}}+(1-\chi)\,\underline{\underline{\varepsilon}}^e$$

to withdraw

time strains $1-\chi$ of creep of the total deflections: éq 6.2-2b the equivalent

$$\breve{\underline{\underline{\varepsilon}}}=\underline{\underline{\varepsilon}}-(1-\chi)\,\underline{\underline{\varepsilon}}^f$$

strain which controls L" damage ε_{eq} in the coupled model is evaluated more starting from the elastic strain but starting from the strains of coupling: éq 6.2-3 corresponding $\breve{\underline{\underline{\varepsilon}}}$

$$\varepsilon_{eq}=\sqrt{\langle\breve{\underline{\underline{\varepsilon}}}\rangle_+:\langle\breve{\underline{\underline{\varepsilon}}}\rangle_+}$$

with

$\langle\,\rangle_+$ the positive part of the tensor. The damage

in tension and compression D_t are calculated as D_c in the case not coupled but with the equivalent strain defined in the equation [éq 6.2-3]: éq 6.2-4a éq 6.2

$$D_c=1-\frac{\varepsilon_{d0}(1-A_c)}{\varepsilon_{eq}}-\frac{A_c}{\exp(B_c(\varepsilon_{eq}-\varepsilon_{d0}))}$$

- 4b () being

$$D_t=1-\frac{\varepsilon_{d0}(1-A_t)}{\varepsilon_{eq}}-\frac{A_t}{\exp(B_t(\varepsilon_{eq}-\varepsilon_{d0}))}$$

materials parameters

$\varepsilon_{d0}, A_c, B_c, A_t, B_t$ *of the model of Mazars. As in the case*

not coupled, a weighted average of these two damages by the coefficient finally makes it possible α_t to calculate the damage: éq 6.2-5a éq D_{n+1} 6.2

$$D_{test}=\alpha_t{}^{\beta}D_t+(1-\alpha_t)^{\beta}D_c$$

- 5b Notons

$$D_{n+1}=\max(D_{n+1},D_{test})$$

that the choice

which was fact is to preserve the determination of the coefficient starting from the elastic strain α_t (and not strains of coupling): éq 6.2-6 where are

$$\alpha_t=\frac{\sum_{i=1}^{3}\left[\langle\varepsilon_i^e\rangle_+\varepsilon_{ti}\right]}{\left(\varepsilon_{eq}^e\right)^2}$$

the clean

ε_i^e strains of the elastic tensor; the components of the tensor ε_{ti} are calculated $\underline{\underline{\varepsilon_t}}$ starting from the eigenvalues of the elastic stresses with the following $\sigma_i^{'}$ elastic relation: éq 6.2-7 and is

$$\varepsilon_{ti} = \frac{1+\nu}{E}\left\langle \sigma_i^{'} \right\rangle_+ - \frac{\nu}{E}\left(\left\langle \sigma_i^{'} \right\rangle_+\right)$$ the elastic

ε_{eq}^e strain equivalent, calculated starting from the elastic strain tensor: éq 6.2-8 Note: $\underline{\underline{\varepsilon}}^e$

$$\varepsilon_{eq}^e = \sqrt{\left\langle \underline{\underline{\varepsilon}}^e \right\rangle_+ : \left\langle \underline{\underline{\varepsilon}}^e \right\rangle_+}$$: By adopting

the elastic statement [éq 6.2-8], one finds the conditions of the model of MAZARS: for the pure $\alpha_t=1$ tension and pure $\alpha_t=0$ compression. Put in work in the frame of

6.2 a modelization in deformation gradient the association

of a creep model with a model of damage does not make it possible to regularize the problem of damage: as in the absence of coupling, one observes a pathological dependence with the mesh (see the documentsde référence Aster [R7.01.08] and [R 5.04.02). This is why, the coupling was also carried out for the regularized version of the model of damage of Mazars. The assumptions

selected are identical to the local version, with the result that: the computation of the strains
- of creep is identical since it does not depend on the damage the computation of
- the damage is done in a way similar to the not coupled version. The only difference is that the equivalent strain which controls the damage is obtained starting from the strain tensor of coupling by the following relation: éq 6.3-1 where is

$$\underline{\underline{\varepsilon}} = \underline{\underline{\bar{\varepsilon}}} - (1-\chi)\underline{\underline{\varepsilon}}^f$$ the regularized

$\underline{\underline{\bar{\varepsilon}}}$ strain tensor obtained by the following relation [R5.04.02]: éq 6.3-2 the equivalent

$$\underline{\underline{\varepsilon}} = \underline{\underline{\bar{\varepsilon}}} - c\nabla^2 \underline{\underline{\bar{\varepsilon}}}$$

strain is still found ε_{eq} using the relation [éq 6.2-3], with the limits. The damage $0 \le \chi \le 1$

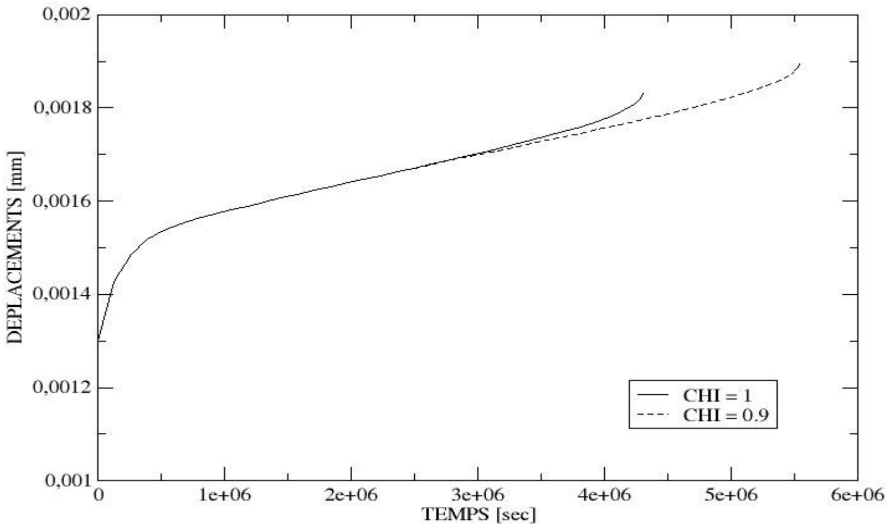
is then calculated D_{n+1} by [éq 6.2-4a, B], [éq 6.2-5a, B], [éq 6.2-6]. In the case not coupled, the coefficient αt is found from the local elastic strain. One preserves this choice in the coupled case. Consequently, its statement is still given by [éq 6.2-6], [éq 6.2-7], [éq 6.2-8], which makes it possible to find the conditions for the pure $\alpha_t = 1$ tension and the pure $\alpha_t = 0$ compression of the model of Mazars. Response in tension

6.3 One proposes here

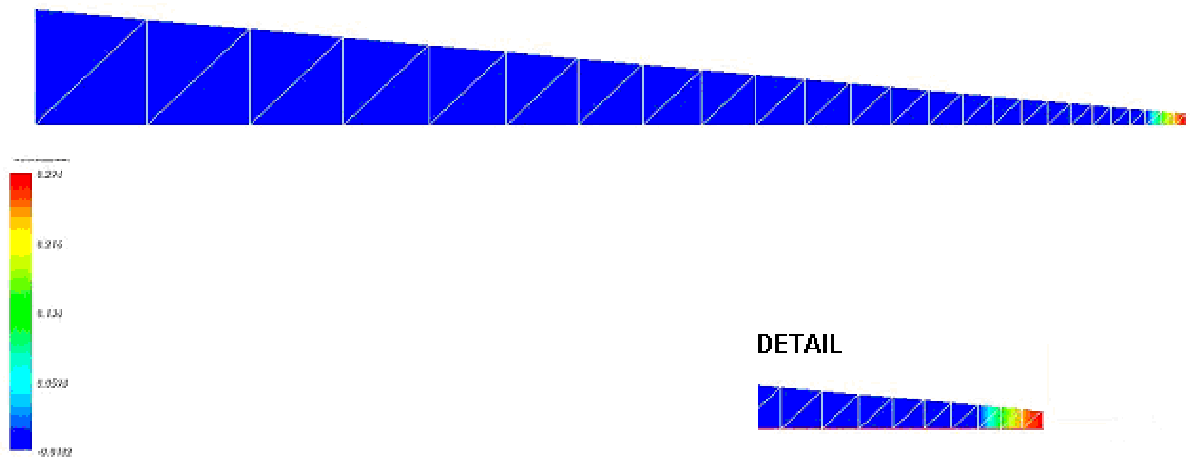
an example of response obtained with the model coupled. It is about a bar with variable section, blocked at an end and with a load of tension applied at the loose lead. On figure 6.4

- 2, one represented the card of the damage at the end of computation for; on figure $\chi=1$ 6.4-1, one shows the response force-displacement obtained for two values of (1 and 0.9). One recognizes χ the curve of tertiary creep well, with the final fracture of the sample. It is shown here that

, in tension, the coefficient of coupling affects especially the time of the fracture. Figure 6.4-1: response



in tension on a bar for two values of the coefficient of coupling. Figure 6.4-2: damage



on a bar where one applied a tensile force (=1). Description χ of

7 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 Shrinkage of desiccation
	, component 11 10 Shrinkage of desiccation
	, component 22 11 Shrinkage 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 Shrinkage of desiccation
	, component 12 19 Shrinkage of desiccation
	, component 13 20 Shrinkage of desiccation
	, component 23 Notations tensor

8 of the total

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

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

$\underline{\underline{\varepsilon}}^{e}$ left spherical

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

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

$\varepsilon_{i}^{fs}\underline{\underline{1}}$ irreversible the tensor of the strains of clean creep left deviatoric

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

$\underline{\underline{\varepsilon}}_{r}^{fd}$ reversible the tensor of the strains of clean creep (contribution of absorptive water) irreversible deviatoric

$\underline{\underline{\varepsilon}}_{i}^{fd}$ part of the tensor of the strains of clean creep (contribution of free water) tensor of the total

$\underline{\underline{\sigma}}$ stresses left spherical

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

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

h intern elastic modulus
K of stiffness to thermal expansion stiffness connects

k_r^s associated with the squelette formed by blocks with hydrates on a mesoscopic scale stiffness connect

k_i^s associated intrinsically with the hydrates on a microscopic scale stiffness associated

k_r^d with the capacity with water adsorbed to transmit loads (load bearing toilets*) elastic*

μ shear modulus viscosity connect

η_i^s associated with the mechanism with diffusion interlamellaire viscosity connect

η_r^s associated with the mechanism with diffusion within capillary porosity viscosity with

η_i^d free water. viscosity associated

η_r^d with the water adsorbed by the averages with hydrates indicate

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

$x_n, x_{n+1}, \Delta x_n$ the value of quantity X at time, *the time* and t_n the variation t_{n+1} of during the interval x . Bibliography $[t_n ; t_{n+1}]$ BENBOUDJEMA

9 F.

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10 This document relates to

constitutive law BETON_UMLV_FP (key word `COMP_INCR` of STAT_NON_LINE) `and` its `associated material` BETON_UMLV_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 the model BETON_UMLV_FP Not documented `SSNV180`	Taken into account
of	thermal thermal expansion and the creep of desiccation in the model BETON_UMLV_FP [V6.04.180 `] SSNV181 Checking`	
of the good	taking into account of the shears in the model BETON_UMLV_FP [V6.04.181 `] And by`	the cases following

tests in the case of coupling: Model coupled ENDO_ISOT_BETON

SSLA103			
`F Computation of the shrinkage`	of	desiccation and the endogenous shrinkage on a cylinder [V3.06.103] ENDO_ISOT_BETON	MAZARS
`SSNV169 Coupling creep`	– damage	[V6.04.169] Description	of the versions

11 of the document Version Aster Author (

S) or contributor	**(S), organization Description of modifications**	**7.1 Y. Pope EDF/R & D**
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