FORMATION ITech
Code_Aster et Salomé-Méca –
module 4 : Génie Civil
(ARN3960)

Recherche & Développement
2-3 mai 2016
Part 1 – Overview on civil engineering models
OUTLINE

- Types of analysis
- Modeling and constitutive laws
- Special Loadings/Boundary conditions
- Pre/Post Processing tools
- Some examples
OUTLINE

- Types of analysis
- Modeling and constitutive laws
- Special Loadings/Boundary conditions
- Pre/Post Processing tools
- Some examples
« STATIC » ANALYSIS

- Linear or non-linear thermal calculation (THER_LINEAIRE, 3D/PLAN/COQUE or THER_NON_LINE, PLAN/3D only)
- Thermo-hydration of the concrete (THER_NON_LINE, PLAN/3D only)
- Drying of the concrete (THER_NON_LINE (diffusion only) / STAT_NON_LINE THH calculations, PLAN/3D only)
- Linear or non-linear static calculation (MECA_STATIQUE or STAT_NON_LINE)
- Chained calculations
  - Thermal + static analysis (including structural elements)
  - Thermal + thermo-hydration + static analysis
  - Thermal + drying analysis + static analysis (excluding structural elements)
  - Thermal + Thermo-hydration + drying analysis + static analysis

- Coupled THHM calculations for porous media (STAT_NON_LINE, concrete only, 2D/3D)
SEISMIC ANALYSIS

- Spectral method by modal synthesis ➔ COMB_SISM_MODAL
  - “Design“ method
  - Linear calculations only

- Vibration dynamics DYNA_VIBRA
  - By Harmonic methods
  - By Transient methods
  - With modal basis
  - With physical basis
    - Localized nonlinearities: shock, friction

- Transient dynamics ➔ DYNA_NON_LINE
  - Behavior nonlinearities: plasticity
  - Geometric nonlinearity: large displacements, friction
OTHERS

- Calculation of reinforcement by the Capra and Maury method `CALC_FERRAILLAGE`

- Impact analysis in explicit dynamic `CALC_EUROPLEXUS` (interface with EUROPLEXUS)

- Flow of a fluid in a cracked concrete structure in 2D `MACR_ECREVISSE`
OUTLINE

- Types of analysis
- Modeling and constitutive laws
- Special Loadings/Boundary conditions
- Pre/Post Processing tools
- Some examples
Several types of finite elements for describing concrete

- The isoparametric finite elements: 2D (triangle or quadrangle, linear or quadratic) or 3D (hexahedron, tetrahedron, pentahedron, pyramid, linear or quadratic)

- Plates: **DKT** (triangle or quadrangle linear)

- Shells: **COQUE_3D** (quadrangle or triangle square)

- Euler beams: **POU_D_E**

- Timoshenko beams: **POU_D_T, POU_C_T**

Ability to use the connections between models: **3D_POU, 2D_POU, COQ_POU, PLAQ_POU_ORTH, LIAISON_DDL (AFFE_CHAR_MECA/LIAISON_ELEM)**
THE FINITE ELEMENTS MODELS (MECHANICS)

Several types of finite elements for describing steel

- **3D/2D**
- 1D elements: **BARRE** (3D), **2D_BARRE** (2D) or beam elements (**POU_D_T**, **POU_E_T**)
- Plate elements: **GRILLE_MEMBRANE** (3D), **MEMBRANE** (3D), **GRILLE_EXCENTREE** (DKT)

Models for reinforced concrete

- Multi-fiber beams (**POU_D_EM**)
- **DKTG** plates
CONSTITUTIVE LAWS FOR CONCRETE

Elasticity with shrinkage optionally taken into account

- Thermal strains
- Drying shrinkage
- Endogenous shrinkage

\[ \varepsilon^{th} = \alpha(T - T_{ref}) \]
\[ \varepsilon^{rd} = -\kappa(C_0 - C') \]
\[ \varepsilon^{re} = -\beta \xi \]

The temperature \( T \), the water concentration \( C \) and the hydration \( \xi \) are control variables.

Be careful! \( T \) is the only control variable for the structural elements.
CONSTITUTIVE LAWS FOR CREEP OF CONCRETE (1/2)

- **GRANGER_FP (_V) (_INDT) [R7.01.01]**
  - basic creep (+ aging effect) (independent of temperature)
  - group in series of Kelvin models (8) (linear viscoelasticity)

\[
\varepsilon^f(t) = J(t, t_e, T, h) \left[ \left(1 + v_f\right)\sigma - v_f t_r(\sigma) I \right]
\]

\[
J(t, t_e, T, h) = h \frac{T - 248}{45} \sum_{s=1}^{r} J_s \left(1 - \exp \left[-\frac{t_{eq} - t_c}{\tau_s}\right]\right)
\]

- **BETON_UMLV_FP [R7.01.06]**
  - Basic creep + drying creep + shrinkage
  - Non-linear model based on the work of F. Bendboudjema in Marne-la-Vallee + Bazant model for drying creep

\[
\varepsilon^s = h f(\sigma^s) \quad \text{and} \quad \varepsilon^d = h f(\sigma^d)
\]
CONSTITUTIVE LAWS FOR CREEP OF CONCRETE (2/2)

**BETON_BURGER_FP [R7.01.35]**
- Basic creep + drying creep + shrinkage
- Non-linear model developed by EDF+ Bazant model for drying creep
- Better control of the 3D-effect and the long-term evolution of the creep

\[ \varepsilon^s = h f (\sigma^s) \quad \text{and} \quad \varepsilon^d = h f (\sigma^d) \]

**FLUA_PORO_BETON [R7.01.36]**
- Basic creep + drying creep + shrinkage
- Non-linear model developed by A. Sellier, LMDC

Plug-in Salomé ARCADE for the identification (in progress)
CONSTITUTIVE LAWS FOR CONCRETE: CRACKING

- Modeling damage or cracking of the concrete is not easy.
  - Problems of reliability, robustness and performance!
  - No universal model - choose your model according to the problem you want to solve!

Biaxial strength envelop [Lee et al.]

Cyclic response (1D)
CONSTITUTIVE LAWS FOR CONCRETE: CRACKING

- Non-linear elasticity

<table>
<thead>
<tr>
<th>Constitutive law</th>
<th>Model</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>BETON_REGLE_PR [R7.01.27]</td>
<td>2D (local)</td>
<td>2D variation of regulatory law BAEL91</td>
</tr>
</tbody>
</table>

- Cohesive zone model

<table>
<thead>
<tr>
<th>Constitutive law</th>
<th>Model</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>CZM_EXP_MIX [R7.02.11]</td>
<td>3D_INTERFACE, PLAN_INTERFACE, AXIS_INTERFACE</td>
<td>Paths of cracking are pre-defined</td>
</tr>
</tbody>
</table>
CONSTITUTIVE LAWS FOR CONCRETE: CRACKING

- Isotropic damage

<table>
<thead>
<tr>
<th>Constitutive law</th>
<th>Model</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENDO_FISS_EXP [R5.03.18]</td>
<td>GRAD_VARI</td>
<td>Isotropic damage tension / compression + restoration of stiffness in compression (V13)</td>
</tr>
<tr>
<td>ENDO_ISOT_BETON [R7.01.04]</td>
<td>Local/GRAD_EPSI/GRAD_VARI</td>
<td>Isotropic damage in tension + restoration of stiffness in compression</td>
</tr>
<tr>
<td>MAZARS [R7.01.08]</td>
<td>Local/GRAD_EPSI</td>
<td>Isotropic damage tension / compression</td>
</tr>
<tr>
<td>MAZARS_GC [R5.03.09]</td>
<td>Local 1D or C_PLAN</td>
<td>Isotropic damage tension / compression</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Restoration of stiffness in compression for 1D</td>
</tr>
</tbody>
</table>
CONSTITUTIVE LAWS FOR CONCRETE: CRACKING

- **Orthotropic damage**

<table>
<thead>
<tr>
<th>Constitutive law</th>
<th>Model</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENDO_ORTH_BETON [R7.01.09]</td>
<td>Local/ GRAD_EPSI</td>
<td>Orthotropic damage + restoration of stiffness in compression</td>
</tr>
</tbody>
</table>

- **Plasticity**

<table>
<thead>
<tr>
<th>Constitutive law</th>
<th>Model</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>BETON_DOUBLE_DP [R7.01.03]</td>
<td>Local (regularization with the Hillerborg method)</td>
<td>Plasticity</td>
</tr>
</tbody>
</table>
CONSTITUTIVE LAWS FOR CONCRETE: CRACKING

- Orthotropic damage + plasticity

<table>
<thead>
<tr>
<th>Constitutive law</th>
<th>Model</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>BETON_RAG [R7.01.26]</td>
<td>3D (local + regularization with the Hillerborg method)</td>
<td>Visco-elastoplastic damage model under the effect of the alkali-aggregate reaction</td>
</tr>
<tr>
<td>ENDO_PORO_BETON [R7.01.36]</td>
<td>3D (local + regularization with the Hillerborg method)</td>
<td>Visco-elastoplastic damage model</td>
</tr>
</tbody>
</table>
## Constitutive Laws for Reinforced Concrete

<table>
<thead>
<tr>
<th>Constitutive law</th>
<th>Model</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLRC_DM [R7.01.32]</td>
<td>DKTG</td>
<td>For a moderate damage</td>
</tr>
<tr>
<td>GLRC_DAMAGE [R7.01.31]</td>
<td>DKTG</td>
<td>For impacts</td>
</tr>
<tr>
<td>DHRC [R7.01.33]</td>
<td>DKTG</td>
<td>Damage + residual strains</td>
</tr>
</tbody>
</table>
CONSTITUTIVE LAWS FOR STEELS

Grid reinforcement of concrete
- GRILLE_CINE_LINE, GRILLE_ISOT_LINE, GRILLE_PINTO_MEN
- and ... all the 1D constitutive laws
- if 1D not possible: ALGO_1D = 'DEBORST'

1D elements
- ELAS_VMIS.ISOT.LINE, VMIS.CINE.LINE, PINTO_MENEGOTTO (elasto-plasticity + Bauschinger effect), CORR.ACIER (damageable elasto-plasticity with plastic deformation at fracture depends on the rate of corrosion)
- and ... all the constitutive laws through ALGO_1D = 'DEBORST'

Pinto-Menegotto behavior
NOTE : JOINT FINITE ELEMENTS

Possibility of using joint (or interface) elements to represent interfaces

- Concrete-steel bond:
  - Constitutive law JOINT_BA (fine model) [R7.01.21] : D_PLAN or AXIS for steel and concrete
  - Constitutive law : CZM_LAB_MIX [R7.01.21] : (GRILLE_)MEMBRANE for steel and 3D for concrete

- Joints between dams elements in 2D or 3D [R7.01.25] – in statics and dynamics:
  - JOINT_MECA_RUPT laws based on a cohesive formulation of failure
  - JOINT_MECA_FROT : elastoplastic version of the Mohr-Coulomb friction law
CONSTITUTIVE LAWS FOR SOILS : CONSISTENT WITH THM MODELS

- Behavior of soils/clay
  - ELAS_GONF
  - CAM_CLAY, BARCELONE
  - CJS, HUJEUX, MOHR_COULOMB

- Elastoplastic behavior of rocks
  - MOHR_COULOMB
  - DRUCK_PRAGER, DRUCK_PRAG_N_A
  - LAIGLE, HOEK_BROWN (_EFF) (_TOT)

- Viscoplastic behavior of rocks
  - VISC_DRUC_PRAG, LETK, LKR (soon)

- Thermo-hydro-mechanical coupling (porous media)
  - KIT_HM, KIT_HHM, KIT_THM, KIT_THHM (hyp : isotropy or orthotropy)
SOME REMARKS

- Help for the identification of some behavior laws
  - Macro-command `DEFI_MATER_GC` for MAZARS and `ENDO_FISS_EXP`
  - Macro-command `CALC_ESSAI_GEOMECA` to easily simulate typical test (0D)
  - In-progress: plug-in for DHRC and `BETON_BURGER_FP`

- V&V file for paraseismic computations: see [A4.01.04]
  - Behaviour laws concerned: `GLRC_DM`, `MAZARS_GC` and `ENDO_ISOT_BETON` (in progress)
  - Structures: SMART model, benchmark SAFE, a fuel building, ....
OUTLINE

- Types of analysis
- Modeling and constitutive laws
- Special Loadings/Boundary conditions
- Pre/Post Processing tools
- Some examples
SOIL-STRUCTURE / STRUCTURE-SOIL-STRUCTURE INTERACTION

- Meshing the soil -> behaviour: **ELAS, MOHR-COULOMB, HUJEUX,** …

- Ground springs method: **RIGI_PARASOL,** to define with **AFFE_CARA_ELEM** (model **DIS_T** or **DIS_TR**)

- Coupling MISS3D / Code_Aster: **RIGI_MISS_3D,** to define with **AFFE_CARA_ELEM** (model **DIS_T**)

Aster Génie Civil | 02/05/2016 | 25
LOADINGS/BC WITH TO 0D ELEMENTS

- contact with impact or friction:
  model DIS_T or DIS_TR with the behaviour DIS_CHOC or DIS_CONTACT

- To take into account some equipments on a surface through distribute masses:
  model DIS_T with CARA_ELEM/MASS_REP

- To connect 2 models with AFFE_CHAR_MECA:
  - Keyword LIAISON_ELEM : 3D_POU, 2D_POU, COQ_POU, PLAQ_POU_ORTH, LIAISON_DDL,
  - Keyword LIAISON_MAIL : TYPE_RACCORD: ‘COQUE_MASSIF’, ‘MASSIF_COQUE’
  - Keyword LIAISON_COQUE
TENSIONING PRESTRESSING TENDONS

- Possibility of "automated" treatment of the tendons especially for the tensioning phase (phasing possible) for 1D elements thanks to:
  - **DEFI_CABLE_BP** / **CALC_PRECONT**

**BARRE** modeling
- For describing grouted tendons (perfect cable-concrete bond)
- Tension to be applied in tendons calculated by BPEL91 or ETCC-2010 formula

**CABLE_GAINE** modeling
- For describing slipping tendons (with or without friction)
- Tension obtained by the simulation of the tensioning procedure
Tension profil for a « circular » tendon : Comparison of different modelings

More details in the slides « Modeling of the prestressed reinforced concrete »
OUTLINE

- Types of analysis
- Modeling and constitutive laws
- Special Loadings/Boundary conditions
- Pre/Post Processing tools
- Some examples
PRE/POST-PROCESSING TOOLS

Visualization of the geometry of structural elements

EFICAS View 3D
Géométrie et trièdres
PRE/POST-PROCESSING TOOLS

Vizualisation of the stress field or strain field with Paravis for multi-fiber elements (POU_D_EM) and multi-layer elements (DKT)

Command IMPR_RESU_SP

- archive tar.tgz

- open with Paravis the file .pvd

Example: crossarm of a lattice tower

SSNL135A/SV1.01.01 §7
Vizualisation of the orientation of structural elements

Command **IMPR_RESU**(FORMAT='MED', CONCEPT=_F(CARA_ELEM=cara, REPERE_LOCAL='OUI', MODELE=MO) )

-> resu.med

open with Paravis:

- CellCenter Filter

- Glyph Filter for REPLO_1, REPLO_2, REPLO_3
PRE/POST-PROCESSING TOOLS

NEW in Salome-Meca 2016 vizualisation of \((F_{\text{int}}, M_{\text{int}})\); see [U7.05.21], §6

\(\text{IMPR\_RESU(FORMAT='MED', CONCEPT=_F(CARA\_ELEM=cara, REPERE\_LOCAL='ELNO', MODELE='MO'))}\)

+ \(\text{IMPR\_RESU(FORMAT='MED..) of the field EFGE\_ELNO}\)

open with Paravis
Calculation of strains (**CALC_CHAMP**)

- **EPsi_ELGA / EPSI_ELNO** : total strains
- **EPme_ELGA / EPME_ELNO** : mechanical strains
- **EPVC_ELNO or EPVC_ELGA** : strains due to control variables (hydration, drying, temperature)
- **EPFP_ELGA / EPFP_ELNO** : creep strains (**BETON_UMLV_FP**, **BETON_BURGER_FP** or **GRANGER** laws)
- **EPFD_ELNO / EPFD_ELGA** : drying creep strains (**BETON_UMLV_FP**, **BETON_BURGER_FP** laws)
- **DEGE_ELNO** : generalized strains (linear elasticity)
PRE/POST-PROCESSING TOOLS

For stresses calculation

- SIEF_ELGA / SIEF_ELNO: stresses
- EFGE_ELGA / EFGE_ELNO: generalized forces
- SIPO_ELNO: Computation of the stresses in the section of beam broken up into contributions of each generalized force.
- SIRO_ELEM: the normal and tangential stresses to the faces of the elements, calculated at the center of faces \((\text{SIG}_N, \text{SIG}_T1, \text{SIG}_T2)\)

Visualization of stresses
PRE/POST-PROCESSING TOOLS

- For the calculation of stresses in structural elements
  - **SIGM_ELNO**
  - **EFGE_ELNO**: structural efforts
  - **EFCA_ELNO**: structural efforts in the global coordinate
  - **SIPO_ELNO**: stresses in the beam section decomposed into contribution of each structural effort in the local coordinate system (SN, SMFY, SMFZ, SVY, SVZ, SMT)
  - **SICO_ELNO**: stresses in a layer of shell elements

- A command
  - **POST_COQUE**: to extract the efforts at any point of a shell (SSLS126B)
PRE/POST-PROCESSING TOOLS

- Energy calculations (total energy, kinetic energy, ...)
  - Work in progress

- Dissipation (DISS_ELNO / DISS_ELGA) for the GLRC_DM law

- Calculation of masses (POST_ELEM / MASSE)

For dynamic calculations:

- Keyword OBSERVATION to accurately track the evolution of a quantity in the calculation without storing all time steps
HOW-TO DOCUMENTS

- Panorama of the tools available to carry out civil engineering analysis
  - U2.03.07

- General tips for using the operator `STAT_NON_LINE/DYNA_NON_LINE`
  - U2.04.01 / U2.06.13

- General tips for structural elements
  - U2.02.01 (plates, shells, ...), U2.02.03 (discrete elements)

- A civil engineering study with tendons
  - U2.03.06

- A civil engineering study with seismic loading
  - U2.06.10

- Several documents for modeling the Soil-structure interaction (SSI)
  - U2.06.05, U2.06.07, U2.06.08 [restricted access], U2.06.12 [restricted access]

- Performing damage calculations in quasi-static analysis
  - U2.05.06

- Etc …
OUTLINE

- Types of analysis
- Modeling and constitutive laws
- Special Loadings/Boundary conditions
- Pre/Post Processing tools
- Some examples
SIMULATE THE AGING OF A REINFORCED CONCRETE STRUCTURE OVER 60 YEARS

Applied loads over time

- Tension CH
- Tension CV
- Dome
- VC1
- VD1
- VD2
- VD3
- VD4
- VD5
- VD6

Thermal dilatation
Drying shrinkage
Endogenous shrinkage
Creep / drying creep (BETON_UMLV_FP)
SIMULATE THE AGING OF A REINFORCED CONCRETE STRUCTURE OVER 60 YEARS

- 3D concrete
- Reinforcing steel
- Prestressing cables
SIMULATE THE AGING OF A REINFORCED CONCRETE STRUCTURE OVER 60 YEARS

Evolution de la concentration en eau dans l'épaisseur, au cours du temps

Perte de tension dans les câbles

déformation orthoradiale à coeur

EPStt
déformation totale
déformation fluage propre
déformation fluage dessiccation
CREEP BEHAVIOUR OF CONTAINMENT BUILDING

Comparison of computed and experimental strain

View of the 3D model

Data fitting to predict the future behaviour
ILLUSTRATION : BEHAVIOR IN CASE OF SEVERE ACCIDENT

First step : strain at 60 years (creep)

Second step : stress with high pressure (~0.5 MPa) and high temperature (150°C)
SIMULATION OF A BEAM AT EARLY AGE + 4-POINTS FLEXION TEST

Free shrinkage beam: 4-point flexion test 48 days after casting

The results are satisfying for temperature at early age

Results obtained with Code_Aster (local isotropic damage model)
SIMULATION OF A 3 - POINTS BENDING TEST ON A REINFORCED BEAM WITH CZM

Ouverture moyenne : 234 µm
STUDY OF COOLING TOWERS

Amplified displacement of a cooling tower under wind load (shell)
MECHANICAL BEHAVIOR OF CONCRETE PIPES WITH METAL WEB

Impact of corrosion on the mechanical resistance

- Cracking
- Plastification of reinforcement bars
- Corrosion of the metal pipe web

Map of damage + deformations

Test device
A TGV ON AN AGING PRESTRESSED CONCRETE BRIDGE

- Vertical accelerations at ballast
  - multifiber beam
  - cracking
  - dynamic
  - rolling load

![Graph showing dynamic behavior](image-url)
SEISMIC CALCULATION WITH CODE_ASTER

Taiwan 1999
EXAMPLES OF USE

Reinforced concrete structures

- nonlinear GLRC_DM constitutive law
EXAMPLES OF USE

Metallic structures
EXAMPLES OF USE

- Pipes

- Tanks (containing fluid)
SEISMIC CALCULATION OF DAMS

- Taking into account the energy dissipated in the soil and dam waters: Soil-Structure Interaction, Soil-Fluid-Structure Interaction

Mode of an arch dam

Stresses in a dam under seismic loading
EARTH-FILLED DAM SIMULATION

Layered construction

Watering

Seismic loading
SIMULATION OF THE ALKALI-AGGREGATE REACTION (RAG)

- Validation on an industrial case: an existing dam segment
SIMULATION OF A CONCRETE DAM

- Modeling of the joining up(*) and the friction between arch dam segments
- Hydromechanical modeling of the joint between the rock and the dam foundation

* The joining up consists to fill the joints between the blocks at the end of construction of dam by grouting, to ensure the transmission of forces to the rock
End of presentation

Is something missing or unclear in this document?
Or feeling happy to have read such a clear tutorial?

Please, we welcome any feedbacks about Code_Aster training materials. Do not hesitate to share with us your comments on the Code_Aster forum dedicated_thread.
Thanks