

Code_Aster[®]

Analysis of
Structures and
Thermomechanics for
Studies & Research

www.code-aster.org

Code_Aster's Possibilities

Code_Aster offers a full range of multiphysical analysis and modelling methods that go well beyond the standard functions of a thermomechanical calculation code: from seismic analysis to porous media via acoustics, fatigue, stochastic dynamics, etc. Its modelling, algorithms and solvers are constantly under construction to improve and complete them (1,200,000 lines of code, 200 operators). Resolutely open, it is linked, coupled and encapsulated in numerous ways.

■ Phenomena

> Mechanical

- Static, quasi-static, linear or otherwise
- Dynamic, linear or otherwise, on a physical or modal basis
- Fracture, damage and fatigue
- Soil-Structure, Fluid-Structure and Soil-Fluid-Structure interactions

> Thermal

- Stationary, transient, linear or otherwise
- Fixed or moving reference coordinate system

> Associated phenomena

- Acoustics
- Metallurgy
- Hydration and drying

■ Analysis Types

> Standard

> Decomposition into Fourier modes

> Substructuring

> Model superposing, multiscale

> Adaptive mesh

> Sensitivity calculation

> Fitting and optimization

> Mechanical reliability calculation

■ Multiphysical

> Internal links with thermics

- Hydration, drying
- Metallurgy

> Internal links with mechanics

- Thermal
- Metallurgy
- Hydration and drying

> Internal couplings

- Thermo-hydro mechanical
- Fluid-Structure

> External coupling with other codes

- Soil-(Fluid)-Structure (MISS3D)

> External links with other codes

- Hydraulics: Code_Saturne
- Thermal: SYRTHES
- Electromagnetism: Flux2D/3D
- Fast dynamics: EUROPLEXUS

■ Loadings

> Mechanical

- Nodal or distributed forces
- Pressure
- Inertia loading
- Centrifugal acceleration
- Imposed movements
- Anelastic strain
- Effect of wind

> Thermal

- Temperature
- Flows, linear or otherwise
- Forced convection
- Exchange between walls
- Heating by Joule effect

> Specific loads (following forces, electromagnetic forces, initial states)

■ Nonlinearities in static and dynamic

> Geometrics

- Geometric updating, large displacements, large rotations
- Following forces
- Continuation methods: in displacement, by arc length, in strain, by criterion output
- Load discharge and non-radiality indicators
- Contact and friction: by a discrete contact method (active stresses, penalization, conjugated projected gradient or by an augmented Lagrangian method.)
- First order buckling

> Materials (95 constitutive laws)

- Linear and nonlinear elasticity
- Nonlinear hyperelasticity
- Local elastoplasticity and elastoplasticity with gradient formulation
- Nonlinear viscoelasticity
- Local and with gradient formulation damage
- Elastoviscoplasticity
- Metallurgical effects
- Material data dependent on temperature, metallurgical condition, hydration, drying and fluence
- Progressive strain
- Hydration, shrinkage and creep of concrete
- Geomaterials

■ Dynamics

> Modal analysis

- With or without damping (viscous, hysteretic, modal)
- Direct or by substructuring
- Normalization, filtering, modal parameters

> Linear transient response

- Direct
- On modal basis
- By substructuring

> Transient response with local nonlinearities (on modal basis)

- Shocks
- Friction
- Fluid blade

> Harmonic response

- Direct
- On modal basis
- By substructuring

> Random response

- Parametric and nonparametric probabilistic
- Stochastics

> Direct nonlinear analysis

- Implicit
- Explicit
- Shocks
- Plasticity, damage
- Contact and friction

> Substructuring

- Conventional or cyclic
- Modal, transient or harmonic analysis

> Seismic analysis

- With shocks or multi-support
- Spectral or transient direct linear or on modal basis
- Modal damping calculation (RCC-G)

> Extrapolation of experimental measurements

- Temporal or frequential

■ Interactions

> Fluid-Structure

- Structure-incompressible flow interaction; turbulent stresses
- Vibro-acoustics (free surface)

> Soil-Structure and Soil-Fluid-Structure

- Absorbent boundary elements
- Frequential coupling with MISS3D

■ Thermal analysis

- > Linear and nonlinear thermics
 - Phase change
 - Hydration and drying
 - Mobile coordinate system resolution
- > Metallurgical changes
 - Steels, Zircaloy
 - Phase hardness calculation
- > Thermal treatments and welding

■ Geotechnical Civil Engineering

- > Constitutive laws for concrete (reinforced or pre-stressed), geomaterials
- > Hydration, drying and basic creep at different time scales
- > Passive reinforcement or pre-stressing effect with elastoplastic behaviour: bar, grids and membrane
- > Creep-cracking coupling
- > Thermohydrmechanics (porous media, formulation in effective stresses, constitutive laws in kit form, etc.)
- > Specific loads (hydric and gaseous flows)
- > Excavation procedure
- > Fracture, damage, fatigue and collapse of structures
- > Global release rate
 - thermoelasticity: G
 - thermoelastoplasticity: GP and GTP
- > Local release rate in 3D
- > Stress intensity factors
- > Models of brittle and ductile fracture, initiation and instability
- > Specific load drive
- > Local and non-local damage
- > Crack modelling: joint element and X-FEM
- > Decoupled damage

- > Fatigue analysis
 - Loading history
 - Counting methods
 - Specific criteria applications
- > Verification of RCC-M criteria
- > Zarka-Casier method in cyclic loading
- > Progressive wear
- > Limit analysis
- > Micro-macro approach: polycrystalline model

■ Survey quality

- > Spatial indicators
 - Mécanique (en résidu pur, par lissage)
 - Thermique (en résidu pur)
- > Mesh refinement/ unrefinement via HOMARD
- > More robust finite elements
 - Mechanics (underintegrated, incompressible)
 - Thermics (lumped modelling)
- > Mesh diagnosis
- > Thermomechanical time step redistribution
- > Sensitivity calculations
 - Mechanical
 - Thermal
 - Depending on materials, loadings and domain variations
- > Parameter fitting
 - Materials or loading
 - Depending on test sampling or digital results.
- > Reliability calculations: probability of exceeding threshold using a FORM type method

■ Modelling

- > Catalogue of material data
- > Connecting incompatible meshes.
- > Superimposing models using the Arlequin method.
- > Modelling connection (3D-shell, beam-pipe, etc.)
- > Plane stress condition adaptable to all models
- > Beam characteristics calculation
- > Homogenization (composites, repetitiveness, etc.)

■ Elements library (400 finite elements)

- > Mechanical
 - 2D, 2D axi (with or without Fourier decomposition), 3D, under-integrated, incompressible
 - Bars, beams (simple or multi-fibre), pipes, plates, shells, membranes, cables, discrete or non-distortable elements
- > Thermics: 2D, 2D axi (with or without Fourier decomposition), 3D, shells
- > Hydration-Drying: 2D, 2D axi, 3D
- > THM Coupling: 2D, 2D axi, 3D

■ Solvers

- > Linear (LDLT, multifrontal, PCG, MUMPS, FETI)
- > Nonlinear (Newton, etc.)
- > Integration schemes (Runge-Kutta, Newmark, adaptatives, etc.)
- > Modals (Power, Lanczos, IRAM, etc.)
- > Extended parameter setting. Several strategies for re-numbering, storage, pre-conditioning, post-verification, etc.

■ Dedicated tools

- > Pipework stacks and elbows ASPIC/ASCOUF
- > Steam Generator Tubes: GEVIBUS

■ Software environment

- > Integration in Salomé
- > Pre- / post processing: I-DEASTM, GIBI, Gmsh, ENSIGHT, Xmgrace
- > Data exchange in MED format
- > Survey management tool and engineering application workshop: ASTK
- > Command File Editor and Syntax Analyser: EFICAS
- > Portable nature of bases
- > Developed command language: PYTHON
 - Loop, test, checking structures, etc.
 - Method, class, etc.
 - Interactive calculation and visualization (mathematic libraries, GUI, scale drawings, etc.)

■ Not forgetting...

- > Software under QA (independent validations, reference of 2,000 test cases, 13,000 pages of documentation, source management, qualification of version, etc.)
- > code-aster.org website (downloads, online documentation, forum, FAQ, examples, etc.)
- > Communication and network (quarterly ASTER 'echos' magazine; User Club, its network of correspondents and the annual day; Free Code_Aster under GPL licence, etc.)

Nonlinear

In an industrial survey it is more and more necessary to take into account nonlinearities of: materials, geometrics and contact.

Through the operators DYN / THER / STAT_NON_LINE Code Aster offers solutions that suit each of these.

Non-linear operators...

... rich in functionalities and user-friendly: DYN_NON_LINE and STAT_NON_LINE make it possible to carry out an implicit static or dynamic survey with kinematic nonlinearities (large transformations, large deformations), nonlinearities resulting from the constitutive law and awareness of the contact/friction.

In thermics, THER_NON_LINE simulates nonlinearities (materials, radiation, forced convection) and makes it possible to calculate the change in the physical composition and dampness of concrete over time.

Power and proficiency

Code_Aster's non-linear mechanics operators are those which most take advantage from the innovations resulting from our development activities in the field of computational mechanics.

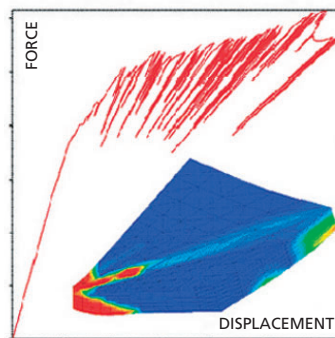
Great efforts are done in order to meet the requirements of the specialists in non-linear mechanical simulation, but also to make the resolution power accessible in the most user-friendly way.

Numerous options thus make the calculating engineer's life easier. He/She has the possibility to check the carrying-out of the calculation, to follow-up real-time numerous interests (stresses, intern variables,

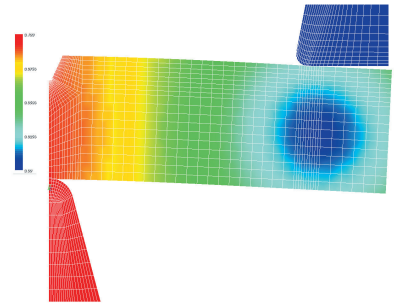
displacements, etc.) and to take advantage from options of the Newton-Raphson algorithm (choice of the matrices and their update, line search, intelligent temporal discretisation, etc.).

Non-linear operators use global criteria of convergence and criteria based on physics reference values (stresses, distortions, etc.) These strong points provide a better comfort of use and more accuracy, especially with heterogeneous residues (mixing of modelling, physics, etc.).

General methods to follow-up the evolution of instable structures or to calculate the maximum load are available: continuation method in displacement or by arc length. Regarding materials with softening behaviour, drive by elastic prediction makes it possible to monitor efficiently the loss in local stability by controlling the most constrained points. Another technic consists in ensuring the continuity of the response in distortion process.



Damage: load drive



In non-linear dynamics, numerous schemes for temporal integration are available (Newmark, HHT, theta-method).

A fitting process (MACR_RECAL) identifies the optimal parameters by comparing the results of an experiment with those of its simulation. Lastly the final relevance of the results may be compared to various sensitivity calculations (SENSIBILITE) and to errors estimations (CALC_ELEM).

Kinematic nonlinearities

Nonlinearities resulting from large displacements may be modelled in various ways (keyword DEFORMATION).

SIMO_MIEHE processes large plastic strains and large rotations, taking into account the whole information resulting from the deformation gradient. It is applicable for various constitutive laws: plasticity with isotropic strain-hardening, viscoplasticity (with changes in the metallurgic phase) and ductile damage (ROUSSELIER model). This model is incrementally objective and therefore makes it possible to process the large rotations without limitations.

GREEN processes large rotations, large displacements and small distortions. This tool makes it possible to use any elastic and incremental behaviour.

PETIT_REAC however solely updates geometrics at each time step (necessarily small) and allows only small rotations.

Code_Aster, an open source software

Nonlinear operators have greatly taken advantage of the source opening of Code_Aster, in terms of feedback from the users as well as for the development of new functionalities.

Among them:

- The "slide" contact, worked out by the IFP (French Petroleum Institute)
- The hyperelastic behaviour (for elastomers): a Mooney-Rivlin model introduced by the Lyons 1 University.

Regarding structure elements, GREEN_GR processes large displacements and large rotations of beams and shells.

REAC_GEOM is used for multi-fibre beams.

Finally the COROTATIONNEL option is used with the external module for the ZMAT constitutive law integration.

Nonlinearities in behaviour

isotropic and anisotropic elasticity, hyperelasticity (Signorini's model, applicable under Mooney Rivlin), plasticity with isotropic/kinematic strain-hardening, elastoviscoplasticity (Chaboche's and Lemaitre's models).

A wide range of behaviour models simulating damage are also available: models for progressive distortion (Taheri's model, polycrystalline model), brittle and ductile damage (Rousselier's model).

Code_Aster also includes models resulting from specific issues: plasticity and damage of concrete, steels and joints, cohesive elements, models for soil and rock mechanics (Cam-Clay, Barcelona and Hujoux models), models for micro-macro homogenization and coupled thermohydrmechanics in kit form.

These behaviours are available for numerous modellings and finite



Nonlinear thermomechanical calculation of a combustion turbine compressor: bladed rotor and quarter compressor.

elements since the De Borst algorithm makes it possible to apply them easily to shells and multi-fibre beams.

If needed, it is also possible to develop a new behaviour model. In order to make the validation process easier SIMU_POINT_MAT, a macro-command has been developed and implemented in V8 (NEW V8).

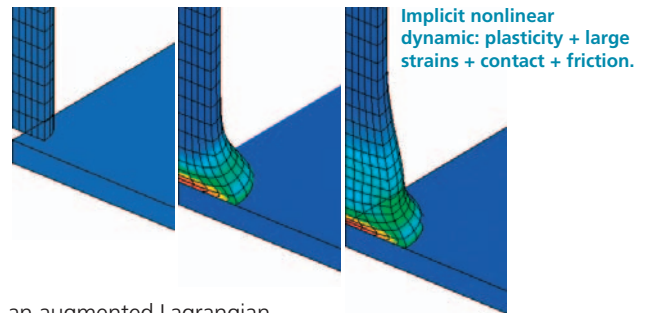
Nonlinearities in contact-friction...

Code_Aster deals with contact/friction in different ways. Its scope of use includes the whole range of modellings (2D/3D, beams and shells), eventually based on incompatible mesh or with updated geometries (large slidings linked to large surfaces).

Traditional discrete formulations (with processing by penalization or dualisation) are available. In the last few years an important work has been made on the algorithms performances. A new iterative algorithm (projected conjugate gradient) has been implemented in the field of frictionless contact. It is now possible to solve problems involving thousands of meshes in contact with brilliant performances (in terms of calculation as well as storage footprint).

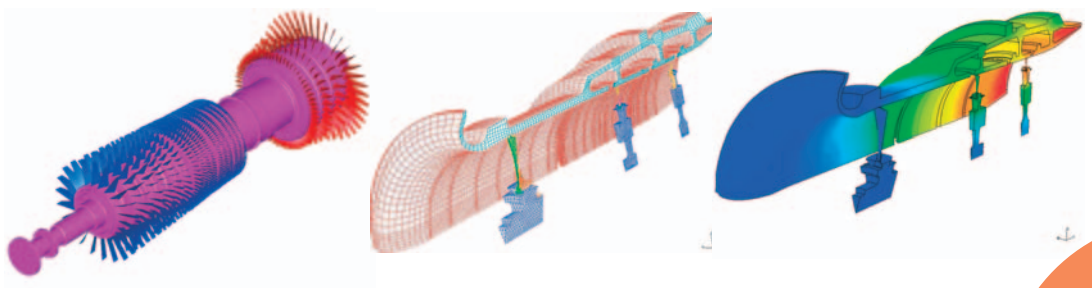
Code_Aster is also fitted with a "continuous" method of contact based on a weak formulation

of the contact/friction problem with three unknown fields (displacement, contact pressure, friction pressure) and using



an augmented Lagrangian formulation. This option is particularly precise in terms of contact physics and also makes it possible to use a model dedicated to micro-asperities (compliance model), which is especially efficient in the processing of shocks in dynamics. This is also a very general option, which may be applicable in simple Lagrangian formulation as well as in penalized formulation through a wise choice of coefficients, while dealing efficiently with the redundancy between boundary conditions and contact conditions.

The creation of fields that store the gaps and reactions values in every potential contact point and which can be displayed in form of isoValue or curves, makes the data processing easier. Finally the use of contact is simplified thanks to a unique access point: AFFE_CHAR_MECA, keyword CONTACT.



Geomaterials

Why is EDF interested in modelling the behaviour of concretes, silts, sands, clays and rocks ?

Because, beyond the behaviour of dams, there is also the appraisal of solutions envisaged for storing radioactive waste.

Code_Aster's thermohydrromechanical models are one of the contributions of EDF to the thorny problem of the downstream of the cycle.

Nonlinear geomaterials under nominal load are often subject to creep deformation: predicting the state of structures in the short and long term therefore requires the simulation of their construction phases. This is particularly true since the behaviour of soaking water through these materials has mechanical consequences, especially on long-term changes to the ground and rocks. It is therefore essential to calculate flows as such, since the capillary effects linked to partially saturated states significantly influence the stress state. This is particularly true for poorly permeable materials, where strong suctions appear.

Special constitutive laws

The phenomenologies described here can, of course, only be simulated by specific models in *Code_Aster*. Beyond their diversity, they all share the property of representing the deterioration of materials under shear according to confinement and accompanied by perceptible volume variations. The formulation framework will vary depending on whether it is a case of a concrete, silt, sand, clay or rock. The formalism of damage is preferred for concretes, the micro-crack formation of which damages rigidity, whereas in the case of ground, plasticity makes it possible to take better account of irreversible strains. The hardening is rendered dependent on volumetric plastic strain for clays and on shear plastic strain for rocks. In all cases, a softening behaviour appears beyond a certain threshold. For grounds and rocks, the functionalities in *Code_Aster* model the concomitant dilatancy phenomena quite closely. They also model hydraulic and thermal changes – these lead directly to

damage such as cracking due to drying, collapse due to remoistening, plasticizing due to clay swelling and ground breakdown due to the thermal dilation of water.

An offering adapted to geomaterials

For sands and silts, the first level of CJS (Cambou, Jeffari, Sidoroff) laws, which is very close to the Mohr-Coulomb criterion, allows an approach of the “load limit” type. The second and third levels introduce a coupling between isotropic and deviatoric plastic mechanisms with isotropic or kinematic hardening including dilatancy and strain-softening for the third level. In the case of saturated clays, Cam Clay (RELATION_KIT='CAM_CLAY'), the star of the models, associates a nonlinear elasticity with a plasticity limiting stresses to a domain, which size depends on the consolidation pressure. Its extension to non-saturated grounds, known as the Barcelona model, makes this domain also dependent on capillary pressure. For rocks, EDF took advantage of the experience of the Hydraulic Engineering Centre of Chambéry (Centre d'Ingénierie Hydraulique), which has demonstrated the need to retain the ‘post-peak’ (i.e. cracked) behaviour of rocks and offered a generalization of the Hoek and Brown model ('LAIGLE'). The Hoek and Brown model, much simpler but approved by the geophysicians, is also available, as well as the Drucker-Prager elastoplastic model for concrete and some kinds of grounds. *Code_Aster* meets the variety of hydraulic phenomena in porous media with simple models for drying and hydrating concrete, or more complex ones based on coupled integration of two nonlinear flow laws and the integration of the energy conservation law.

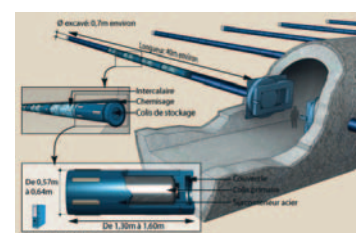


Water saturation map in a medium-level waste slot

In the sophisticated version of these models without gas pressure hypothesis, the exchanges between phases are governed by very general thermodynamics equilibrium laws. The flows are Darcian, with permeabilities and saturation linked by any laws supplied by the user. The same applies to the relationship between saturation and capillary pressure. The distribution mechanisms within gaseous (“dry” gas and vapour) and liquid (dissolved gases and liquid water) mixtures are governed by the Fick laws.

Significant experience and feedback

Significant experience and feedback The age of some of these models and the length of time they have been used have contributed to increasing their robustness. Coupled THM modelling is well suited to the EDF requirements: tightness of the containment vessels of nuclear power stations, problems connected with the deep storage of waste, re-saturation and the thermo-mechanics of swelling clays, damage during excavation and the consolidation of galleries, etc

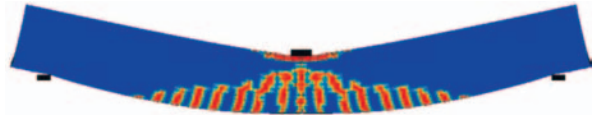


Close-up on a storage gallery – Andra architecture

Optimized architecture in THM

Optimized architecture in THM Major breakthroughs have been achieved lately in the field of THM modelling, especially in optimizing the degrees of freedom of the architecture with a second-order interpolation for mechanics and first-order interpolation for thermo-hydraulics. The numerical integration methodology has also been improved, resulting in the separation of the integration points for the terms of the diffusive kind (Gaussian quadrature) or of the capacitive kind (top of the element). To do this, you have to use the selective modelling, adding an S at the end of its name (i.e. D_PLAN_HMS).

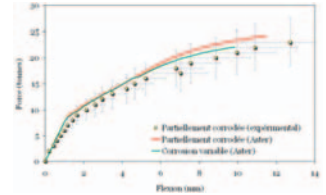
Civil engineering, concrete



Mechanical performance of concrete with web plate pipes. Impact of corrosion on mechanical performance.

Non linear static study including concrete cracking, reinforcements plasticizing and web plate corrosion.

Studies carried out by the NECS company (www.necs.eu) for EDF/MMC.



Behaviour curve of the pipe. Test/Aster simulation comparison.

In forecasting and controlling the mechanical behaviour of civil engineering structures for power production such as the containment vessels, the nuclear power station cooling towers or the dams, EDF's concerns for the safety of the installations are dominant. The resolute positioning of Code_Aster on the nonlinear modelling of pre-stressed reinforced concrete makes it possible to calmly consider digital monitoring of such structures over time.

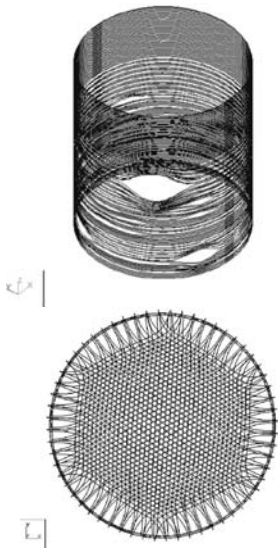
Evaluating the service life of a concrete structure as well as anticipating and correcting its defects require knowledge of its condition at early age or at a given time. This creates interest in the diversity of concrete modellings, the methodology of workable surveys and the experimental validation of these: thermohydration, drying, shrinkage, cracking, damage, creep and the effect of active and passive reinforcements. Beyond physical behaviour, the range of problems to be covered is vast; for example, the tightness of concrete containment vessels for nuclear power stations and their distortion over time, as well as the effects of accidental loads such as earthquakes, loss of primary coolants or shock of projectiles.

It is well suited to models based on elements such as shells, under monotone load, and completes the already existing models: Laborderie (LABORD_1D), Double Drucker Prager (BETON_DOUBLE_DP), Mazars (MAZARS), Badel (ENDO_ISOT_BETON), Godard (ENDO_ORTH_BETON). The damage models may be regulated (GRAD_EPSI) in order to get rid of the numerical dependence to the mesh size. Lastly continuation methods make it possible to overcome potential snap-backs.

Pre-stressed concrete

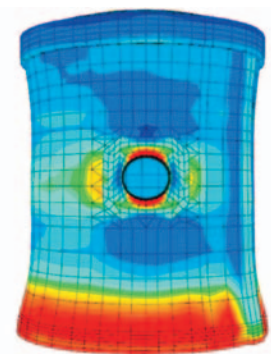
Code_Aster offers various functionalities to analyse the behaviour of pre-stressed structures. The pre-stressed concrete and cables meshes can be meshed separately in order to make this task easier. Thanks to the DEF1_CABLE_BP command, it is possible to link the cables to the concrete, as well as calculate the mandatory tension profile and integrate it into the model. Depending on the kind of study, using the STAT_NON-LINE or CALC_PRECONT commands makes it possible to apply tension to the cables and to phase them.

Concrete reinforcements can be modelled by finite elements of bars or mesh reinforcements. When combined with elements of shells in order to depict tied rebar cage, they may be transformed from the neutral layer surface. A non-linear law can be applied to mesh reinforcements in order to simulate plasticization and non-linear strain mechanisms.



Mesh of pre-stressed cables of a containment building.

Modelling of the shear stresses on concrete: EDF SEPTEN study.

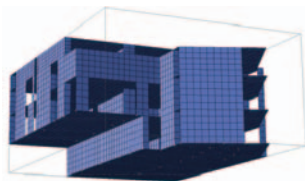


Physico-Mechanical Behaviour of Concrete

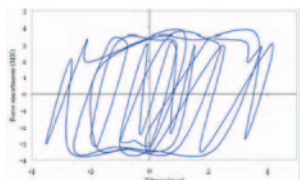
Changes in the properties of concrete are processed by associated thermo-hydration and drying models (Granger, Bazant, Mensi, etc.). The Aster operators calculate concrete shrinkage at an early age from variations in hydration and desiccation shrinkage using a drying calculation. For specific creep, two models are available: GRANGER and BETON_UMLV_FP. Desiccation creep can be modelled using the Bazant's approach which is available either alone (BAZANT_FD) or coupled with the specific creep of the BETON_UMLV_FP law.

Nonlinear mechanical models

The mechanical nonlinear behaviour of concrete is processed by various models that have to be chosen depending on the issue that is dealt with. A new model depicting the "parabolic rectangle" statutory law in 2D (BETON_REGLE_PR) is available.



Resistance to seismic of a public building. Monitoring of the seismic protection support devices. Nonlinear transient dynamic analysis with discrete elements such as linear spring and nonlinear damper. Studies carried out by the NECS company (www.necs.eu).



Force of the dampers during the seismic.



Displacement of the #2 flooring during the seismic

Note

The latest developments of the CORR_ACIER constitutive law for reinforcements (BARRE elements) describing a damageable elasto-plastic behaviour in which the fracture plastic strain depends on the corrosion index.

Fracture, Damage and Fatigue

The analysis of the causes of destruction of a structure or a mechanical component must take into account the actual nature of the deterioration recorded and the degree of fineness being sought. By offering a wide range of models and analysis tools from the most widely tested to the most exploratory, Code_Aster covers the range of problems of damage, fracture, fatigue and limit loads.

For mechanical deterioration under repeated loadings, we speak of "fatigue". Otherwise it is a case of "fracture" or "damage". The mechanics of fracture relies on global criteria for deciding whether an existing crack will propagate, whereas the damage mechanics is directly linked to the materials for the detection of initiation and development of the damaged areas.

■ Cracks development

Two key parameters make it possible to analyse the stability and the propagation of a crack: the energy release rate G and the stress intensity factors K . In *Code_Aster* these parameters can be calculated in linear elasticity thanks to the operators `CALC_G` (energetic method) and `POST_K1_K2_K3` (displacement jumps interpolation), in various situations: 2D and 3D, surface or volume force, pressure on the lips, etc.

In elasto-plasticity it is still possible to use `CALC_G` to calculate G provided that the load remains monotonous and radial. Two new parameters have been implemented in order to go beyond these limits: `GTP` (full-plastic G , calculated with `CALC_G` on breach in ductile fracture) and `GP` (plastic G). The latter, only used for brittle fracture, is an extension of the plasticity in the Francfort-Marigo formulation. The `POST_GP` operator makes it possible to identify the critical values of GP and predict the moment of fracture for a given thermo-mechanic transient.

An approach based on elements of joint (`PLAN_JOINT` model) or discontinuity elements (`PLAN_ELDI` model) makes it possible to model the development of two-dimensional cracks in a given direction, in static as well as in dynamics, with an interface model of the cohesive zone kind (taking into account residual interaction between the crack lips, `CZM_EXP` or `CZM_EXP_REG` behaviour).

■ Damage of structures

Cracking according to an interface law is just a mode of deterioration, the damage mechanics make finer modelling possible because it uses the material point scale.

If we limit ourselves to the study of initiation in the strictest sense of the word, the operator `POST_ELEM` supplies a probability thanks to the WEIBULL model.

However if we want to model the entire response of the structure, from initiation to destruction, it is essential to resort either to constitutive laws coupling the development of the damage and stresses on the material point scale (`ENDO_ISOT_BETON`, `ENDO_ORTH_BETON` or `MAZARS` criteria for concrete, `ROUSSELIER` for steel) or to softening plasticity models (`BETON_DOUBLE_DP` for concrete, `DRUCKER_PRAGER` for soils and `VENDO_CHAB` for metals).

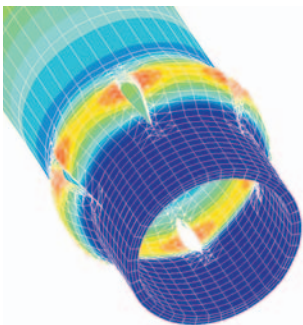
However, if they authorize finer modelling, these laws come up against two difficulties: the instability of the overall response of the structure and the localization of strains. In order to overcome these, *Code_Aster* provides two innovative responses: Specific continuation methods make it possible to monitor instabilities (snap-back/through phenomena) and non-local formulation behaviours avoid pathological dependence on the discretization.

■ Fatigue damage

Most failures of industrial components in normal operation are due to fatigue. Its latent nature is only equalled by its noxiousness, which is why the evaluation of this type of phenomenon is important from the design stage.

Depending on the type of fatigue (low cycle fatigue, high cycle fatigue, etc.) the type of stresses (deterministic, random, periodic, multiaxial, distortions, etc.), available input data (component or stress tensor, etc.) and desired results (field in one point or on the structure, criterion).

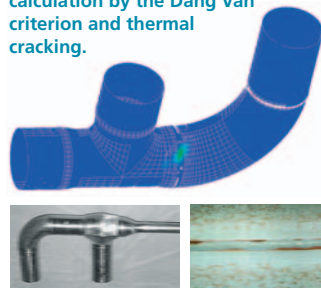
X-FEM method:
multi-cracked pipe.
Post-processing mesh.



Analyse a crack without mesh...

...is now possible thanks to the implementation of the X-FEM method in *Code_Aster*. The crack is defined in a geometrical way (`DEFI_FISS_XFEM` operator) and is introduced into the same mesh by enriching the standard finite elements. In the post-processing of the mechanical calculation, the stress intensity factors may be calculated with the `CALC_G` operator. It is possible to take into account the contact on the crack lips.

RRA circuit elbow: damage calculation by the Dang Van criterion and thermal cracking.



Damage of reinforced concrete

Two new models of damage through bending (`GLRC_DAMAGE` and `GLRC_DM`) have been developed for the static or seismic study of the behaviour of reinforced concrete plates.

Fracture mechanic in modal dynamic

The `POST_K-TRANS` operator makes it possible to identify quickly and accurately the development of the stresses intensity factors over time, in post-processing of a transient dynamic calculation on a modal basis.

Dynamics

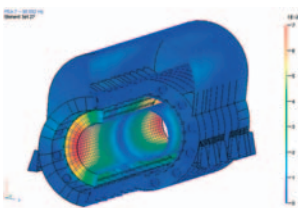
The dynamic behaviour of structures may lead to surprises that are not always pleasant. A simple resonance may have the stress levels of a pump rising! During an earthquake, water surface movements may cause a reservoir to vacillate! Luckily, Code_Aster can help to model the inertia of structures and its unexpected effects during transient or stationary phenomena.

Introducing inertia terms into mechanical equations makes it possible to model the complexity of dynamic phenomena and vibratory or transient aspects. Whether they are deterministic or random, whether the constitutive laws are linear or not, whether or not the distortion of structures are coupled to acoustic or fluid movements, whether components come into contact or chafe, Code_Aster makes it possible to model them on a modal basis or in physical space, on the entire structure or by substructuring.

Modal analysis

Calculating the eigen frequencies and eigen mode of a structure already provides precious information about its vibratory behaviour. The operators MODE_ITER_XX calculate modal deformations and their specific pulses, with or without structural damping. The modes can also be the basis for reducing the model and its main degrees of freedom, thus simplifying the study of transients. It is, of course, possible to normalize modes (NORM_MODE) or to filter them (EXTR_MODE) according to various conventions.

Modal stresses on an alternator model



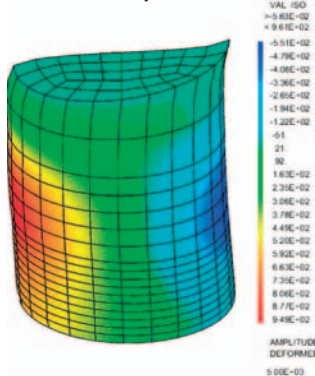
Substructuring for better calculation!

Given the complexity of mechanical structures, conventional numerical or experimental methods often prove to be costly. It is therefore preferable to break down the global model into several substructures and to study their vibratory behaviour separately before connecting them. Different types of interface modes are available in DEFL_INTERF_DYNA: Craig-Bampton, MacNeal or dynamic interface methods. The surface meshes do not even need to be coincident – Code_Aster adapts to incompatible connections. New developments in this field also make it possible to anticipate the impact of a change in structure based on measurements on the initial structure.

Different types of fluid force...

... are modelled in Code_Aster. In vibration under flow (fuel rod), we distinguish two of these: the forces that are independent of movement of the structure and are due to turbulence or to the two-phase nature of the flow (DEFL_SPEC_TURB) and the “fluid-elastics” that give practical expression to the actual fluid-structure coupling (CALC_FLUI_STRU). CALC_MATR_AJOU calculates the coefficients associated with this coupling. It is also possible to study the vibro-acoustic coupling and the rattling of structures filled with liquid (piping, tanks, etc.) with free surface using ad hoc elements (XX_FLUI_PESA/STRU modelling...). This strong coupling is processed by a symmetrical formulation (u, p, f). It is possible to use it in harmonic or directly transient

analysis: the structure may show any type of nonlinearity while the fluid remains modelled in a linear way.



Pressure of fluid in a tank and free surface movement.

Transient or frequential analysis

Knowing the response of the structure to a stimulus is essential for closely analyzing strains and stresses over time. Dedicated operators handle the various process: harmonic linear mechanics (periodical stresses), transient dynamics on a reduced modal basis or physical basis (linear or non-linear, along with numerous integration schemes), spectral analysis and combination of seismic loads or random linear dynamics (interspectral densities).

Dampings

Dissipative phenomena (friction, viscosity, etc.) occur in structures; they have a significant influence on the amplitude of responses. Damping is nevertheless often difficult to model. For this reason, three types of damping are available: viscous, hysteretic and modal.

From measurement to calculation

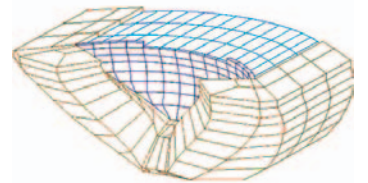
Numerical modelling makes it possible to add to experimental measurements in areas where no sensor is available and where one wants to calculate a stress. PROJ_MESU_MODAL extrapolates the desired value using a modal base from the digital model.

Soil-structure interactions...

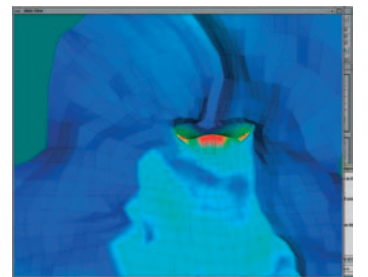
... occurring in reactor buildings or vault dams dynamics may be solved in two ways: by frequential coupling with MISS3D (XX_MISS_3D), integral code equation by ECP, or via absorbent boundary elements modelling quasiinfinite domains (XX_ABSO). In all cases the anechoicity hypothesis is checked (elimination of plane elastic or acoustic waves diffracted by the structure towards infinity).

Acoustics

The survey of acoustic propagation in a compressible fluid and for closed areas is modelled (ACOUSTIQUE phenomenon) via two formulations (conventional and mixed).



Modelling an arch dam in case of a seism: soil-structure coupling between the civil engineering and the tank.



They solve the Helmholtz equation to deduct the noise level and acoustic intensity fields from it.

From multiscale to multiphysics

In the power industry, as elsewhere, the phenomena are often coupled. Code_Aster offers tools for making chainings or couplings of phenomena internally as well as externally with other specialized codes.

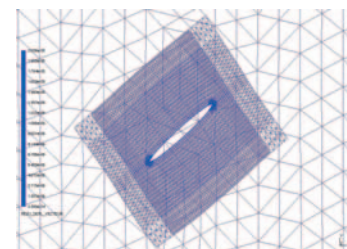
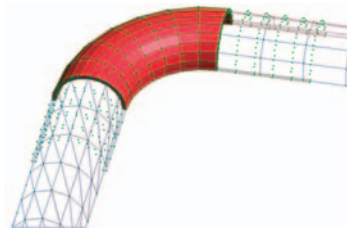
For multiscale and multiphysics, it is possible to distinguish the internal and external approaches of the code. In the first case, the multiplicity of the physics is directly taken into account by Code_Aster, whereas in the other case the interaction is done either by coupling or by chaining with another calculation software.

Internal approaches

Thermomechanical chaining for surveys with materials that depend on temperature or another variable.

By strongly coupling the thermal, hydraulic and mechanical equations (thermo-hydro-mechanical), we are interested in porous media, whether or not these are saturated: rocks, clays, concretes. Thermo-metallo-mechanics, used in particular for the simulation of multipass welding. The fluid-structure interaction makes it possible to calculate the vibrations of a structure containing (or running in) a fluid that is resting or flowing.

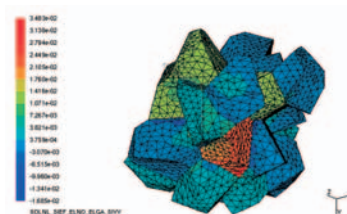
A power-mechanics chaining provides the dynamics of structures subjected to Laplace forces which are induced by the relative positions of the conductors.



3D / shell connection and cracked patch under Arlequin

The Arlequin method opens perspectives for the multiscale by connecting various digital models using a superimposition technique: cracks, welds, support structures, etc.

Cracks may also be analysed without meshing them with the X-FEM method.



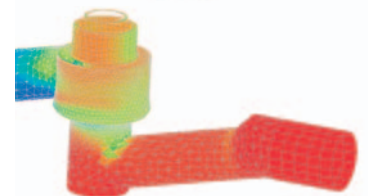
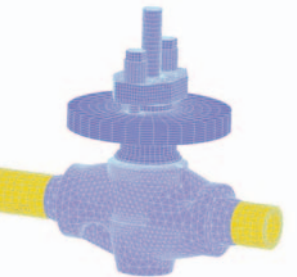
Aggregates calculation

The micro-macro makes it possible to manipulate the constitutive laws in a modular way on diverse scales (see box).

The HOMARD mesh refinement/unrefinement tool combined with the error or sensitivity indicators analysis (calculation of the analytical derivative depending on the data) is a means for the user to judge the calculation quality.

External approaches

Code_Saturne chaining (EDF, thermohydraulics for fluid) – Syrthes (EDF, thermal change for the wall) – Code_Aster (structure) with temperature or pressure field interpolation on the mechanical mesh. Code_Aster – Europlexus



Saturne/Aster chaining

chaining (fast dynamics code from the EDF-CEA-CCR/Ispra-Samtech consortium).

Frequential response by MISS3D (ECP, code of integral equations for wave propagation) to a seismic excitation for stratified soils with or without fluid domain next to the modal analysis with Code_Aster. Importing into Code_Aster of volume stress fields delivered by the electromagnetism code Flux2D/3D with a view to calculating the thermomechanical behaviour of transformers or electric motors.

Thanks to the MED format, Modelling and Data Exchange...

... of finite elements developed by EDF-R&D and the CEA, Code_Aster exchanges meshes, topological entities and results with other codes. The structure of the latter is relatively rich: all types of fields by elements (constant by element, at the Gauss points or at the nodes), fields that are either defined or not defined throughout, and fields involving heterogeneous values components (i.e. a 3D model linked to shells and beams). This richness, which guarantees the opening to the use of non-proprietary pre- and post-processing tools, has a single input point, `FORMAT='MED'`, in `LIRE_MAILLAGE`, `LIRE_CHAMP` and `IMPR_RESU`.

Micro-macro

Defining a behaviour from elementary bricks: a given flowing law, kinematic strain or other isotrope, make it possible to avoid defining all the combined behaviours. Via the operator `DEFI_COMPOR`, these bricks are associated with a monocrystal and its sliding systems, thus creating a behaviour model specific to a group of meshes in `STAT_NON_LINE`.

Calculations of aggregates where every chained grain is made up of an oriented monocrystal can now be carried out. This new "micro-macro" functionality opens the way to a fully modular multiscale. All that needs to be done is to integrate these various scales into a polycrystal made up of several monocrystals and to define a localization rule for the whole thing and the calculation can be started!

Code_Aster, a flexible and open program

With the Code_Aster's architecture, advanced users can easily work on the code, partly thanks to PYTHON, in order to write professional applications, introduce finite elements and constitutive laws or define new exchange formats.

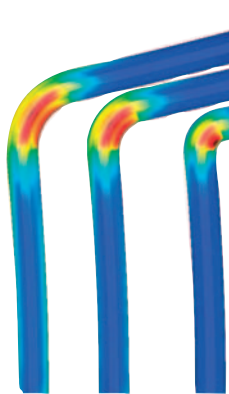
PYTHON commands language

The Code_Aster user describes the parameters and progression of the survey in a command file. The grammar and vocabulary of this language, which is specific to Code_Aster and written in the PYTHON language, are described in catalogues. This structuring of the information makes it possible to enhance the language with new commands at lesser cost or to encapsulate recurring calculation sequences into macro-commands.

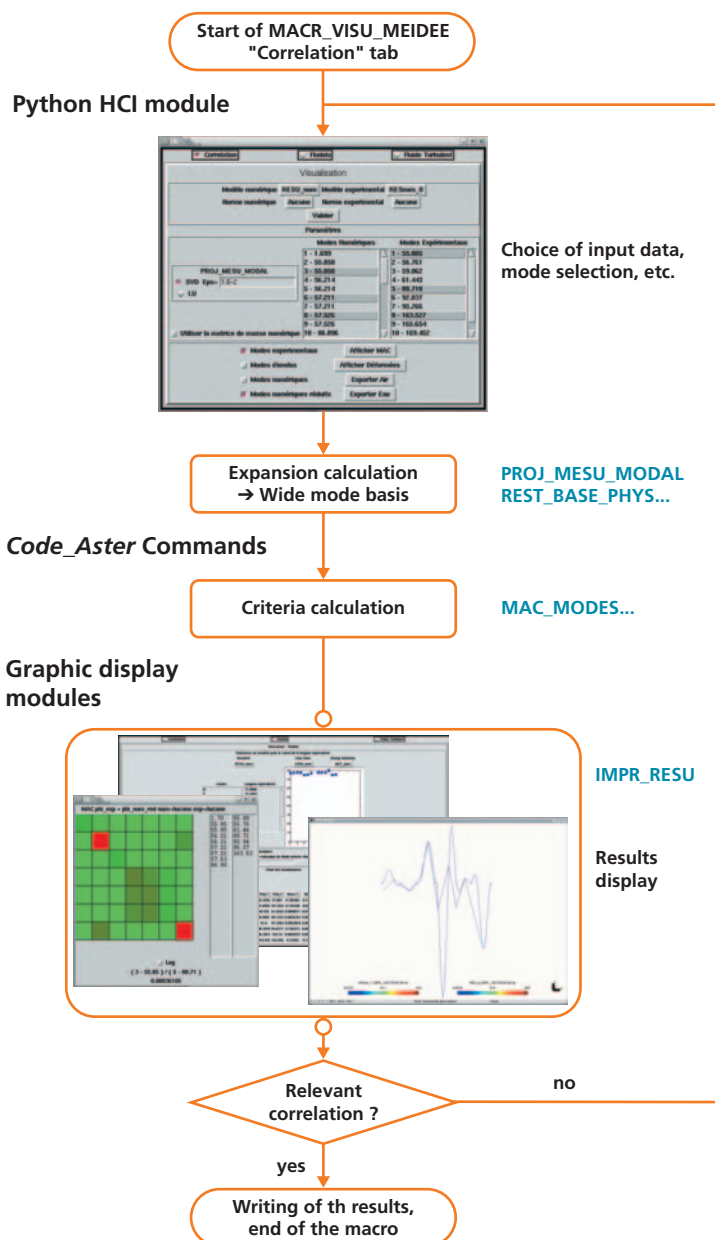
A more advanced use enables users to introduce programming in their datasets: from basic ones (check structures, loop and tests) to more complex ones using all the richness of PYTHON (methods, classes, importing graphics or mathematical calculation modules, etc.)

Here is a first basic example: Optimising a pipe bend-radius. Any calculation result can be uploaded in the PYTHON space. Here we use an indicator for maximal stress in the elbow in order to repeat the mesh, calculation and post-processing tasks, thus optimizing the pipe bend-radius.

Another example: with the MEIDEE macro-command, it is possible to launch calculations for stress identification on wire structure. Using graphics modules provides an intuitive interface that helps proceeding to the identification. By encapsulating it into a macro-command it becomes a professional tool that make the methodology reliable and durable.



Optimization of a bend



Example of use of Python in a macro-command: scheme presenting MACR_VISU_MEIDEE.

Finite elements and constitutive laws

If your problem does not adapt to the hundred constitutive laws currently present, programming or modifying a constitutive law is easy. After consequently enriching the catalogue defining the material parameters, the routine integrating this constitutive law and giving the stress tensor, updated internal

variables, tangent matrices, etc. must be written.

If you do not find a suitable element among the 480 that already exist, you may create your own one. The documentation provides a step-by-step guiding to proceed to this development, which does not require knowledge of the whole application.

Code_Aster, the website and the free version

The www.code-aster.org website, the code's multimedia base, meets the double requirement of being at the service of the users and developers and supporting its distribution as a free program. Guided tour of the sections and categories of the site, taking a look at the technical and political motives of making Code_Aster freely available.

■ Presentation

The Code_Aster, Functionalities and Domains categories resume and develop the chapters of this Code_Aster V8 brochure. The slides presented at the Annual User and Free Code_Aster open days are also available. The Studies example section is devoted to Aster industrial surveys. The distinction between the Free, Development and Operation versions is explained in the Versions section. The Quality control section gives details on the acceptance criteria for changes and corrections. Finally, the Tools section lists programs using or used by Code_Aster.

■ Documentation

The Documentation section provides all the code's technical documentation. The Administration file (quality procedures), the data regarding Materials and the documentation concerning the EDF qualified version are in restricted access in this section. A wiki is available for the free community to write documents to get to know Code_Aster, examples or tutorials coming in addition to the official documentation.

■ Download

This section provides access to downloads of Code_Aster. The source code is provided along with its tools and pre-requisites in a single package called "aster-full", thus making the setup much easier (it often consists in a single command line). The weekly updates of the Development version are also available online.

■ Support

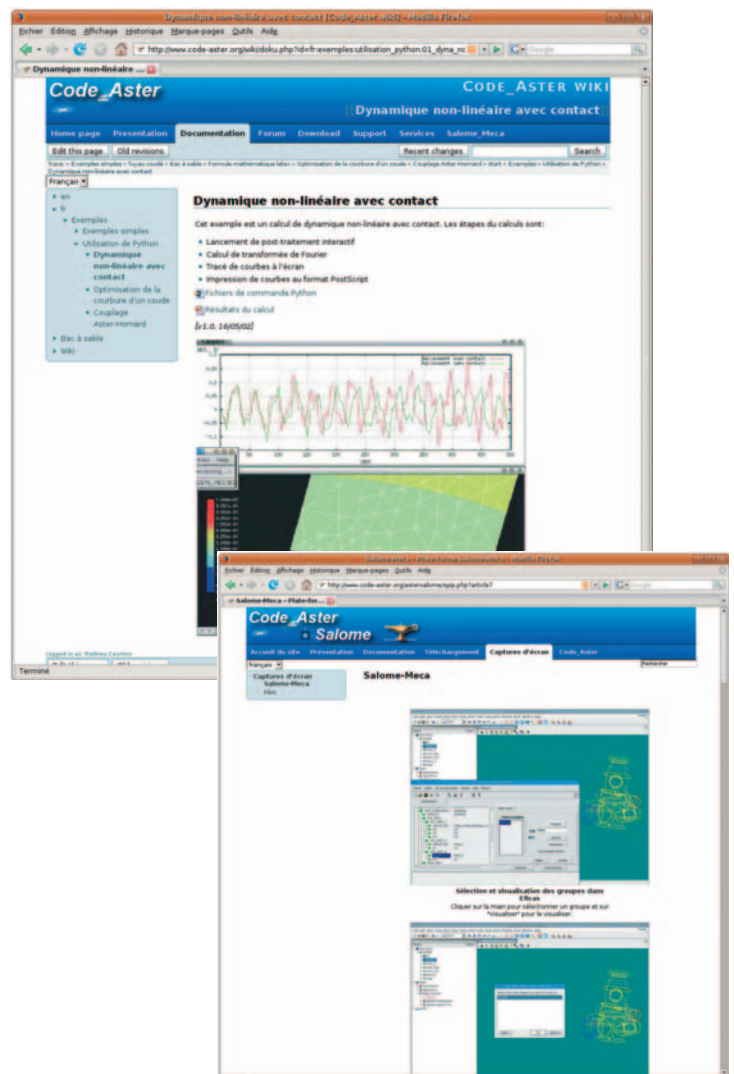
Course material and tutorials from the trainings are available for users. The rules applying to developing and having your development validated within the centralized version are given in

the Presentation section. In Organization, the successive update histories of the development version are available together with reports (restricted access) and an organizational chart of the participants contributing to the code.

In NEW Version you can find information about the setup of a development version.

■ Services

This section has a restricted access and addresses the EDF users and provides all the information concerning access to the code, hotline, trainings and the users club.



A new look

In 2007 the website was rebuilt, using well-tried technologies in order to add new functionalities: wiki, RSS feed, new-looking forum, etc.

Code_Aster as a free software! Why?

The answer is clearly recognition and enhancement through use. Defects are identified fully and more quickly, while diverse know-how and the creativity of professional contributions will finally speed up and guarantee better validation/qualification of models by users of the net-

work. Beyond the technical aspect, the political dimension provided by EDF R&D and its Free Code_Aster under GPL license (General Public License), resulting from the skill and quality requirements in nuclear engineering, is resolutely positioning itself within the innovation – industry transfer. This process is intended to stimulate Aster contributions from both the public and private sectors (see AE no. 43) by offering them in return a sustainable and reusable platform for their own work. Code_Aster can be downloaded biannually and each time benefits from the Aster methodology of non-regression in terms of accuracy and performance.

Products and services

Since 1989, Code_Aster has been recognized within EDF as the digital simulation tool delivering innovations essential to the expert appraisal of problems right in time. Code_Aster confirms its dual mission: a qualified and operational calculation tool that takes on board developments originating in research.

Quality through transparency and validation

The Aster quality criteria, which are governing the development and distribution of the code, are based on a regularly audited quality frame of reference meeting the requirements set by the EDF Nuclear Structures Safety Authority. These criteria constitute the Aster Software Quality Plan and are defined in the code Administration Manual. The theoretical foundations of Aster models are documented in the Reference Manuals. The independent validation of the operational versions of the code, which is carried out by external calculation companies, deals with the software's conformity with regard to its documentation, the actual cover of the declared domains of analysis and non-regression in terms of accuracy/performance. The Quality Sheet enclosed with each operating version is updated per subversion (errors corrected, inclusion of relevant documentation).

A central team of around twenty EDF R&D engineers...

... is devoted to verifying the consistency and quality of the Aster platform (2,000 validation or non-regression tests): architecture, tools, versioning, launching, feedback management, validation, documentation, communication, training, etc. It is also supported by teams in EDF applied projects, industrial and university research and survey and services suppliers. More than 70 engineers have thus contributed to the software's development.

Products

The Aster architecture, comprised of 1,200,000 lines of FORTRAN (440,000 of which are new or

modified in V8), supported by C and Python, is based on a dynamic memory manager, a command "supervisor" and an EF calculation engine (algorithm independent finite element formulation). Its opening relies on wide use of catalogues describing the commands and finite elements.

Code_Aster is available in three forms...

... operation, development and free, all originating from a unique source code. This source along with its tools and prerequisites are maintained and validated under Unix and Linux, but the Free Aster community has suggested the portage under Windows. The Operating Version meets the IPS (Important for Safety) quality requirements. It is subject to corrective maintenance and additional validations and documentation over a two-year period. This is the version for EDF users and their authorized suppliers. It will remain available for 2 more years for resuming surveys. The Development Version is enriched every week by corrections, improvements and innovations (50 updates annually). It will become the Operating Version after a 2-year development cycle and qualification.

Feedback...

... is a precious tool in the development process. It collects user requests, indexes any reports and monitors their changes over time. It uses Intranet technologies in order to manage a database of more than 10,000 records.

More and more...

... calculation resources for Code_Aster users: a centralized Bull Novascale machine (120 processors at 1.6 GHz, 960 GB memory), a

The Linux Aster operation and development files are accessible to EDF and its partners on the centralized server. The biannual version of Code_Aster is edited under GPL license on www.code-aster.org. It originates from the packaging of the current Development version. Weekly patches make it possible to keep it updated.

Documentation

Use (generalities, command syntax, examples), IT Description (architecture, memory management, supervisor, data structures), Reference (formulations and algorithms) and Validation (elementary mechanics or non-regression test examples). In V8: 14,000 pages (50% of the corpus renewed) can be accessed on www.code-aster.org.

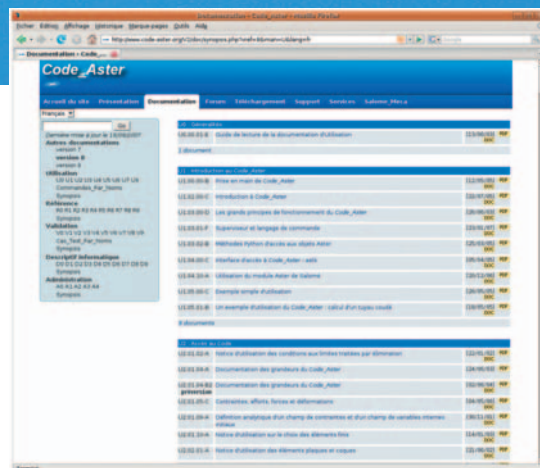
Training and help with modelling

The value of a simulation software also relies on the skill and critical minds of its users. These qualities are acquired through significant initial and ongoing training. Aster courses offer training at all levels: "Initiation" to the code or its "Development", learning to handle "Post-Processing" or "Survey Quality" tools, "Dynamic" and "Static Nonlinear" analyses.

development cluster of 10 Opteron 64 bit processors and access to the massively parallel machines of the Research and Technology Calculation Centre (CCRT) of the CEA.

Aid to use service...

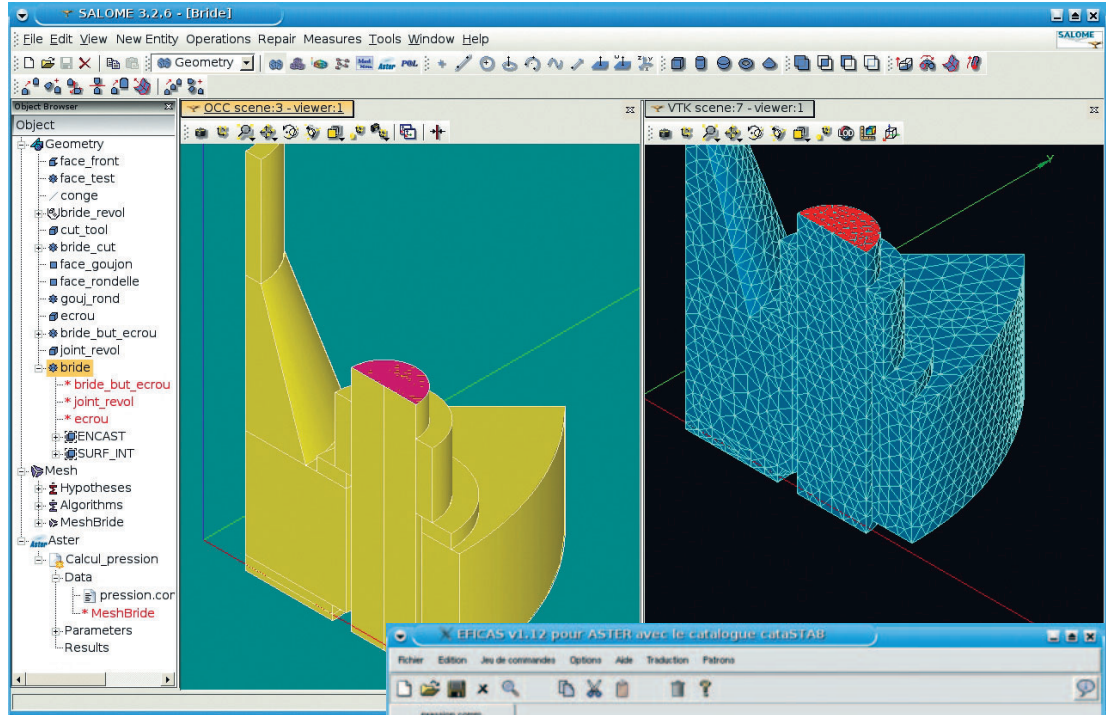
... provides the necessary expertise for complex or innovative studies. May be asked for through the feedback tool.



Code_Aster, a user-friendly

High level calculation is no longer synonymous with "difficult to use".

Today with the integration of Code_Aster into the Salome-Meca platform it is much easier to use the code. Salome-Meca defines, carries out and post-processes your calculation in a few clicks.

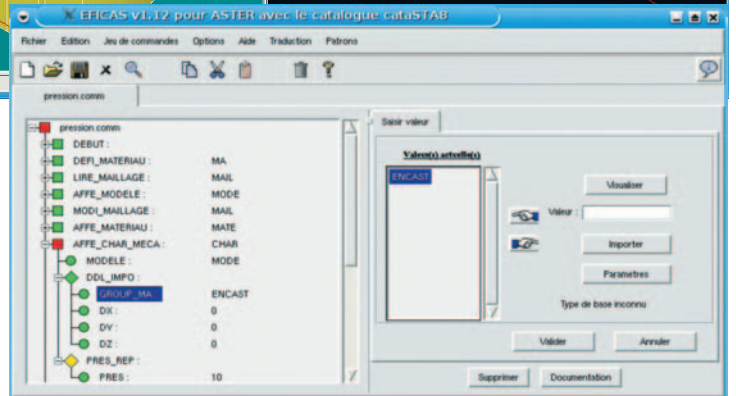


SALOME-MECA: a unique environment for the study steps in Code_Aster.

SALOME-MECA

The Salome-Meca platform offers a unique environment for the various phases of a study:

- Creating the CAD geometry
- Free or structured mesh
- Converting to physical data (EFICAS)
- Launching the Code_Aster calculation case (ASTK)
- Post-processing results (STANLEY)



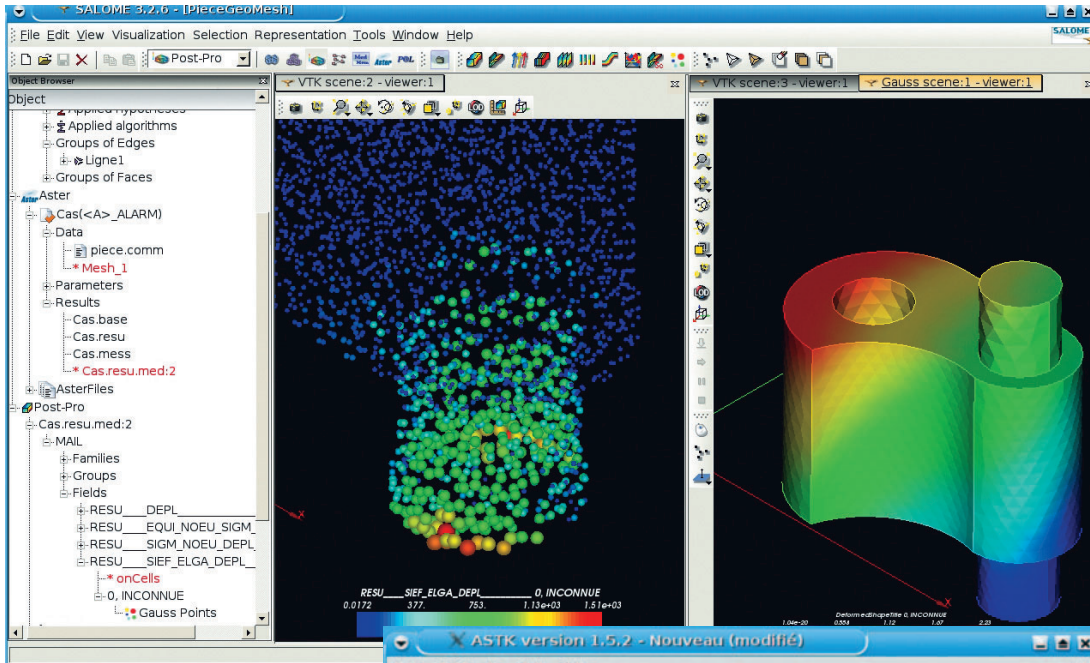
EFICAS: intelligent graphical Aster command editor.

EFICAS

The EFICAS Command File Editor and Syntax Analyser is a software with user-friendly GUI, which directly generates files with guaranteed syntax in accordance with the choices of the user. By interpreting the command catalogues it automatically manages syntax and keywords as well as the various rules and expected concept types.

Integrated to the platform, this software makes it easier to work with mesh groups which are the supports of the boundaries and loads requirements, by selecting them directly on the geometry. For usual studies, an assistant makes it possible to generate automatically a command file according to the few users' choices.

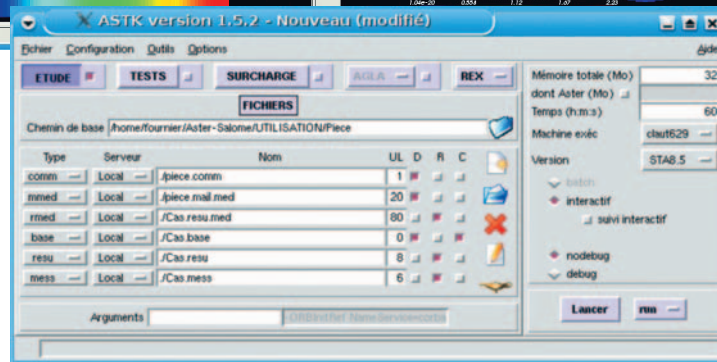
software



SALOME-MECA: results display

ASTK

The provision of a multi-platform, multi-version IT tool that is used and co-developed by various teams has to be done through a Study and Developments Manager. This is ASTK's aim: selecting the code version, defining the files comprised in a study, creating an overloaded version and accessing configuration management tools for developers. This interface uses network protocols for transferring files between clients and server, or for starting remote commands, including over the Internet. Users can easily distribute their data files and results to different machines as the interface ensures the transfer of files, including compressed ones, over the network.



ASTK: the Code_Aster use and development hub.



STANLEY: the Code_Aster results explorer.

STANLEY

The STANLEY application is an interactive post-processing tool that facilitates access to the lists of fields available in the results data structures (displacements, stresses, etc.), calculating new

ones, extracting sub-parts from these and visualizing them in isovalues or curves (Salome-Meca, gmsh, Xmgrace). It adapts to any configuration: workstation under Unix, Linux or Windows, calculation locally or on a remote server.

Code



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