FREE SOFTWARE FOR COMPUTATIONAL MECHANICS: EDF'S CHOICE

Christophe Durand

SUMMARY

EDF, one of the major power utilities, has developed for 15 years its own numerical simulation software for structural analysis, Code_Aster. Widely used, in-house, for the expertise and the maintenance of power plants and electrical networks, this tool covers a large range of applications : 3D thermal analyses and mechanical analyses in linear and non-linear statics and dynamics, for machines, pressure vessels and civil engineering structures ... Beyond the standard functionnalities of a FEM software for solid mechanics, Code_Aster compiles specific research in various fields : fatigue, damage, fracture, contact, geomaterials, porous media, multi-physics coupling … Indeed EDF must justify the lifetime of numerous components and materials, mostly in the nuclear field, that are operated by the company but not designed or manufactured by itself. The problems that EDF has to deal with, requiring specific development, are of three types:

1 taking into account and understanding unforeseen events,

2 quantifying margins with respect to engineering design,

3 justifying the use of a material or a process during a given lifetime.

Thus, EDF must ensure with credibility and in the long run the control of its computational tool, independently of the software publishers. Moreover, developping one's own code guarantees the capitalization of the research and its fast transfer towards engineering, difficult to obtain with a commercial solution. Finally, the continuous effort to develop Code_Aster is justified by our increasing needs in powerful modelings, having recourse most of the time to generalized 3D non-linear computations.

KEYWORDS

3D thermal and mechanical analysis, non linear analysis, free software development, numerical analysis, finite element software

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1: A brief overview of Code_Aster

Developped since 1989 by EDF and for EDF's needs in computational mechanics, Code_Aster has demonstrated it is possible to combine in a unique software two so-called antagonistic aims :

- An efficent software for engineering studies (about 300 users in-house and thousands as free users) with quality assurance requirements
- A numerical platform for software developments products of the EDF's research in various computational mechanics fields.

Being constantly developped, updated and upgraded with new models, Code_Aster represent by now1.200.000 lines of source code, most of it in Fortran and Python.

Justifying quality labels required by nuclear industry, most of the fields of the software have been validated by independant comparisons with analytical or experimental results, benchmarks towards other codes. Moreover, 2.000 tests are managed in configuration : they are devoted to elementary qualification and are useful as examples.

The documentation of Code_Aster represent more than 12.000 pages : user's manuals, theory manuals compiling EDF's know-how in mechanics, example problems, verification manuals. All of these documents are available online at www.code-aster.org

Code_Aster offers a full range of multi-physical analysis and modelling methods that go well beyond the standard functions of a software for computational thermomechanics :

- static and dynamic mechanics, linear or not,
- modal analysis, harmonic and random response, seismic analysis
- acoustics, thermics,
- fracture, damage and fatigue
- multiphysics, drying and hydratation, metallurgy analysis ,soil-structure, fluid-structure interactions,
- geometric and material non linearities, contact and friction,

- a wide range of material properties (95 constitutive laws) : porous media, geomaterials, damage, elastoplasticity, elastoviscoplasticity ...
- a wide range of finite elements (395),
- a wide range of loadings

In the following chapters, we focus on some major applications with Code_Aster, carrying strong ambitions for the modeling capabilities and using the most actual research fields stored in the software.

2: Focus on studies : deformations of a nuclear reactor

Computation of the deformations of a complete reactor after several cycles of irradiation is a major challenge. These calculations include:

- a strong coupling with thermal-hydraulics for vibratory phenomena, taking into account axial and transverse flows,
- generalized multi-body contact between assemblies with rubbing connection rod-grids and guides.
- the simulation of wear at these points of contact,

The expected results are:

- the deformation of the assemblies at the end of the lifetime, in order to validate the maintenance of the systems in operating condition.
- the wear of the rods, acting as the first containment of nuclear-fuel, at the points of contact.

Due to the size of the models and the range of non-linearities to be treated, this calculation is a challenge for the capacities of the software and the computers.

3: Focus on studies : identification of the laws of behavior of steels.

The current models for steel damage, in particular the effect of the irradiation on the nuclear reactor vessel, show their limits to predict the lifespan of this component. They are primarily based on experimental data. The behavior of metal on a very fine scale, the crystal aggregate, even at the atomic scale, should make it possible to represent more finely the behavior of a metallic material at the scale of the continuous media and provides laws and their related parameters used for computational mechanics in Code_Aster.

One identifies the mechanical properties at this intermediate scale via a grid generated randomly, which one affects to each grain its own metallurgical properties. This multi-scales coupling requires a data-processing architecture adapted to build various couples of models [crystal plasticity – homogenization] and, of course, computing power.

The aim is to determine an increase of temperature of the fragile-ductile transition for the elements of a nuclear reactor subjected to irradiation. Today, the tenacity is deduced from a Charpy-test performed on a test-tube CT, the link between tenacity and resilience being empirical.

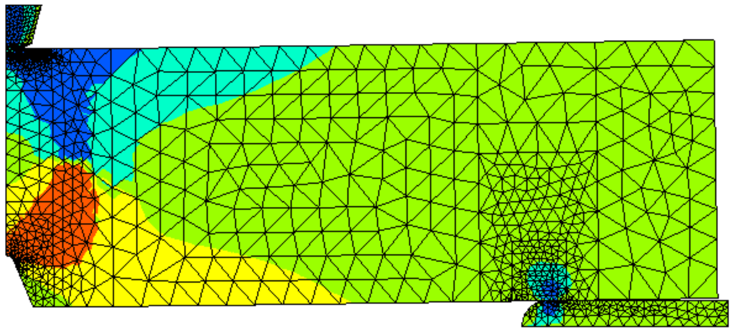

Figure 1: Charpy resilience calculation.

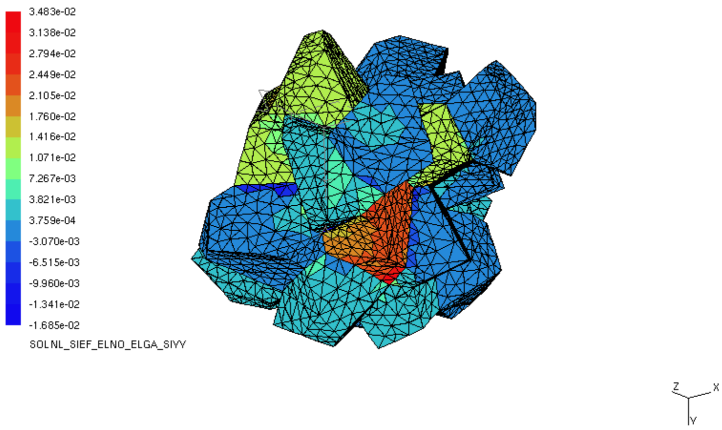

Figure 2: Micro-structure based computation : polycristalline behaviour.

4: Focus on studies : propagation of a 3D-crack in a turbine shaft.

In order to justify the behavior of equipments during their life, a wide class of modeling with Code_Aster refers to the noxiousness of cracks. The regular methods are based on conservative criteria applied on the mechanical analysis of healthy structures. However, the explicit modeling of the crack and its propagation also allows, by a realistic approach, to quantify the margins.

If Code_Aster deals with the modeling of cracks in structures since a long time, these calculations are not easily implemented by engineers because they must anticipate, from the CAD and the meshing step, the presence of the crack. Improvements of productivity are awaited from a description of the crack by a patch [Arlequin method] or by level-sets [the mesh independant approach XFEM]. With these approachs, only healthy structures needs to be represented, facilitating parametric studies on the characteristics of the crack : length, localization and way of propagation. Moreover, the Arlequin method permits also any localization of singularity at a scale lower than that of the model: inclusion, hole… or simple structural zoom.

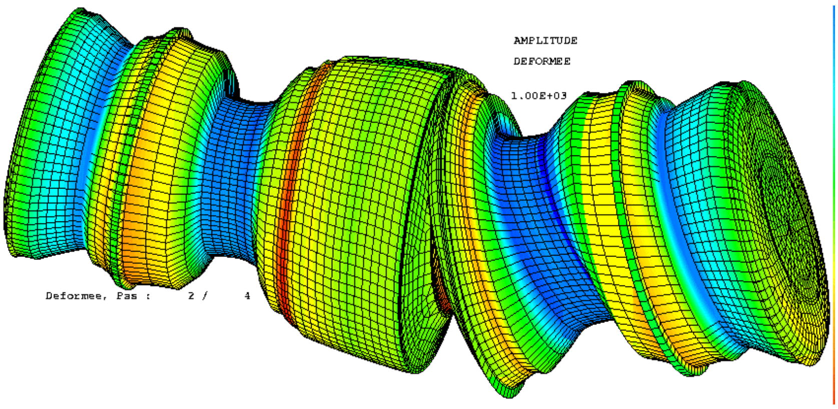

Figure 3: Propagation of crack in a turbine shaft.

5: Focus on studies : concrete crack on prestressed pressure containment vessels.

The lifetime of pressure vessels can be impacted by problems like the sealing, the increase in the deformations in time, and mechanical resistance towards the external aggressions.

3D studies of vessels permit to integrate all the interactions which exist between prestressing, creep, cracking (models of damage), boundary conditions with the dome and the foundation raft, for finally evaluating safety margins (sealing and deformations). And thus to measure the effect of the repeated pressure-tests, to apprehend the efficiency of repairs and to anticipate work. The computation of all possible scenarios helps the operator to take decisions with the best economic conditions.

The challenges in modelling consists in the concomitant use of nonlinear phenomena in the same calculation : essentially damage and contact. Also, the distortion of geometrical dimensions between the overall model (vessel of about ten meters) and the fine and local phenomenon (cracks, damage, steel-concrete connections) generates large models, expensive in CPU and difficult to handle for interpretation. This problem is also true for the cracked structures of the preceding chapter.

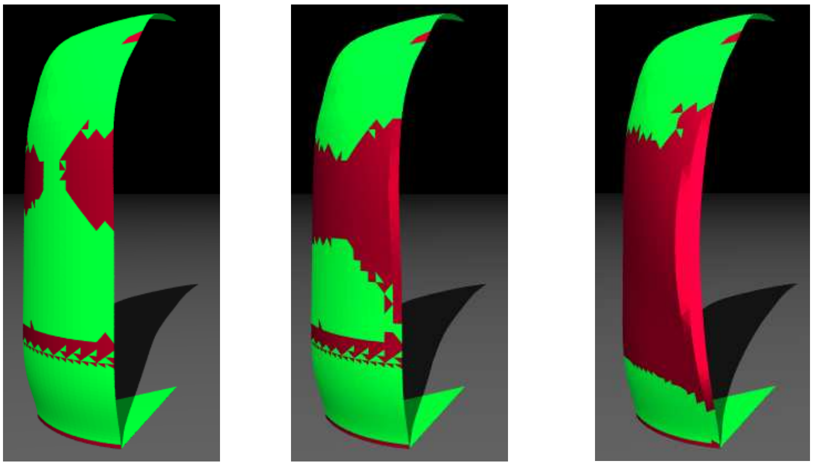

Figure 4: Damage rate calculation in a reinforced concrete vessel.

6: Focus on studies : 3D -computation of the excavation, cracking, re-saturation and potential flow in the damaged zones of a storage-site.

Within the research framework related to the storage of HAVL (high activity and long life) nuclear waste, ANDRA and CEA develop Alliance for the simulation of the various phenomena to be taken into account (diffusion, transport, chemicals, thermal-hydro-mechanics,…). EDF collaborates with ANDRA in order to develop in Code_Aster unsaturated thermal-hydro-mechanical analyzes. These multi-physics modellings deal with difficult numerical problems (stiff fronts for the hydraulic phenomena, localization of the deformations due to the softening behaviour). They require the integration of laws for geomaterial materials and the total management of physics (with strong couplings such as damage-permeability).

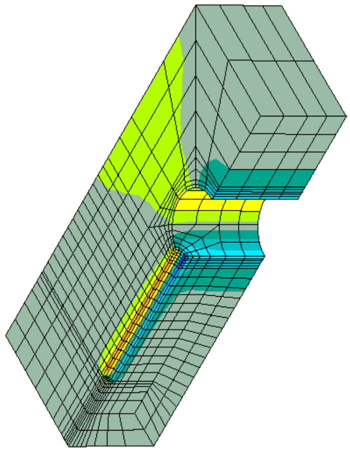

Figure 5: thermal – hydraulic – mechanical state 10 years after having placed waste materials.

7: A free software

Since 2001, Code_Aster is distributed as a free software (GNU general public licence). In addition to the software itself and its open source code, all documentation is freely accessible. In the same way, a very rich database of test cases and tutorials is supplied : any user can easily find data models close to his problems. After five years and in spite of an interface and a documentation still in french, Code_Aster succeded to spread worldwide and now federates a significant network of users on its website : http://www.code-aster.org/. This community is constantly growing as testifies the number of downloads for each new version (nnnnn in all since 2001). Benefiting from the skills and the quality requirements of the nuclear engineering industry, the software is appreciated by manufacturers, technical centers, research teams, service suppliers, teachers. It has been implemented in various industrial fields sometimes very distant from those of EDF : geology, aircraft and car industries, bio-mechanics ...

The motivations of EDF to diffuse Code_Aster as a free software are the following :

1 increase the quality of the code thanks to a validation by the use : benchmarks, recognition as a reference software for valuation in mechanics ;

2 increase the competence tank thanks to an extended use by universities and partner laboratories, by companies providing counsel and assistance to

EDF in computational mechanics, by industrial partners and by PHD students, trainees and new recruits ;

3 most of all, give birth to partnerships and co-developments on applied or generic functionalities. Indeed, we encourage those that adopted Code_Aster to share their coding efforts, their works, and the associated costs of research and development, in a free-software spirit.