CODE_BRIGHT/GID: A 3-D PROGRAM FOR THERMO-HYDRO-MECHANICAL ANALYSIS IN GEOLOGICAL MEDIA

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SUMMARY: Code_Bright/GiD, a 3-D program for the thermo-hydro-mechanical analysis in geological media is described. Code_Bright is a Finite Element code which solves any partial set of 5 equations: stress equilibrium, water mass balance, air mass balance, energy balance and balance of conservative solute. The high number of variables and the strong coupling between them requires special interface features. GiD has been used to build such an interface. Theoretical bases and numerical strategies of the finite element model and elements of GiD interface are presented. The example of the 3-D thermo-mechanical analysis of an *in situ* test simulating a radioactive repository in creeping salt rock is finally described.

CODE PRESENTATION

Theoretical basis

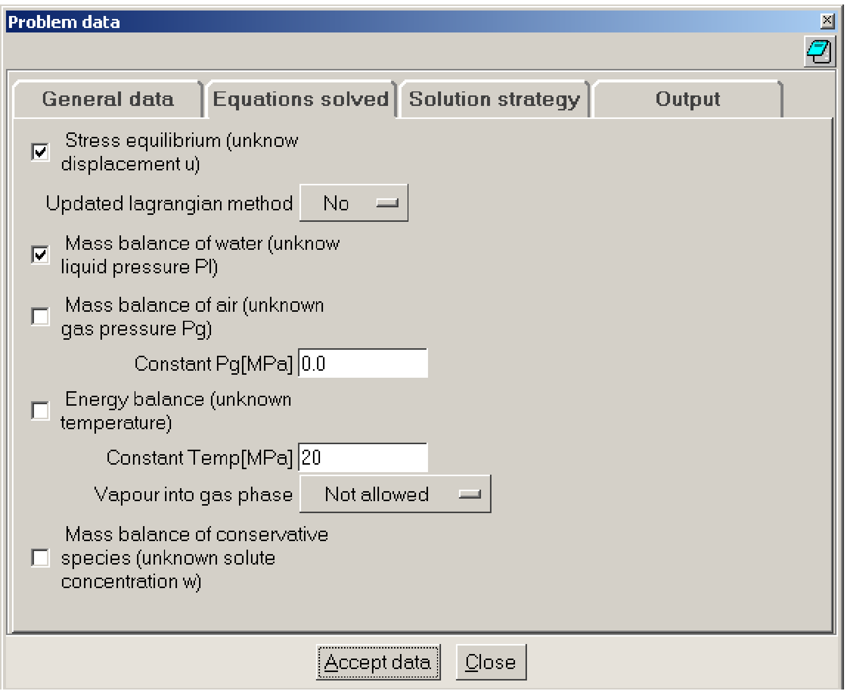
CODE_BRIGHT is a Finite Element program designed to handle thermo-hydro-mechanical (THM) coupled problems in geological media. It solves in the most general case an Initial Boundary Value Problem consisting in a set of five governing equations (stress equilibrium, water mass balance, air mass balance, energy balance and balance of conservative solute), but the possibility exists to solve a partial set of equations. Model can account for large displacements, dissolution process of air into water, advective and non-advective flux of species and energy and water phase changes. Such complex problems require the consideration of a significant number of constitutive laws defining both uncoupled and coupled behaviour for all the variables.

Numerical solution

Special numerical techniques are used to handle this highly non-linear problem. Distinct treatments of storage, advective and diffusive terms are implemented in the discrete model. A mass conservative scheme is considered. Full Newton-Raphson is used to cope with the non-linearities. Direct and iterative solvers with sparse matrix storage can be alternatively selected by the user. Parallel version of the program is available.

Pre-and post-processing

To handle in a user-friendly way the large amount of information required to define the problem, CODE_BRIGHT uses GiD system for pre- and post-processing. CODE_BRIGHT interface follows GiD standards and considered 4 problem-wise windows: the general problem data window, the material parameter window, the initial and boundary problem window and the interval windows. To simplify the input data task, field dependencies are set within the windows. An example of the sheet defining the set of equations to be solved within the Problem data window is shown in Figure 1. The check boxes selected in this sheet determine the number of parameters to be entered. In Figure 2, an example of the Material window is depicted. Constitutive relationships are divided into mechanical, hydraulic and thermal and physical laws. Due to the strong coupling between variables, up to 27 laws may be selected, some of then defined by 10 parameters. The code finally allows considering changes in material parameters and boundary conditions between time steps, which required a special implementation within GiD.



☑ Stress equilibrium (unknow displacement u)

Updated lagrangian method: No

☑ Mass balance of water (unknow liquid pressure Pl)

☐ Mass balance of air (unknown gas pressure Pg)

Constant Pg[MPa] 0.0

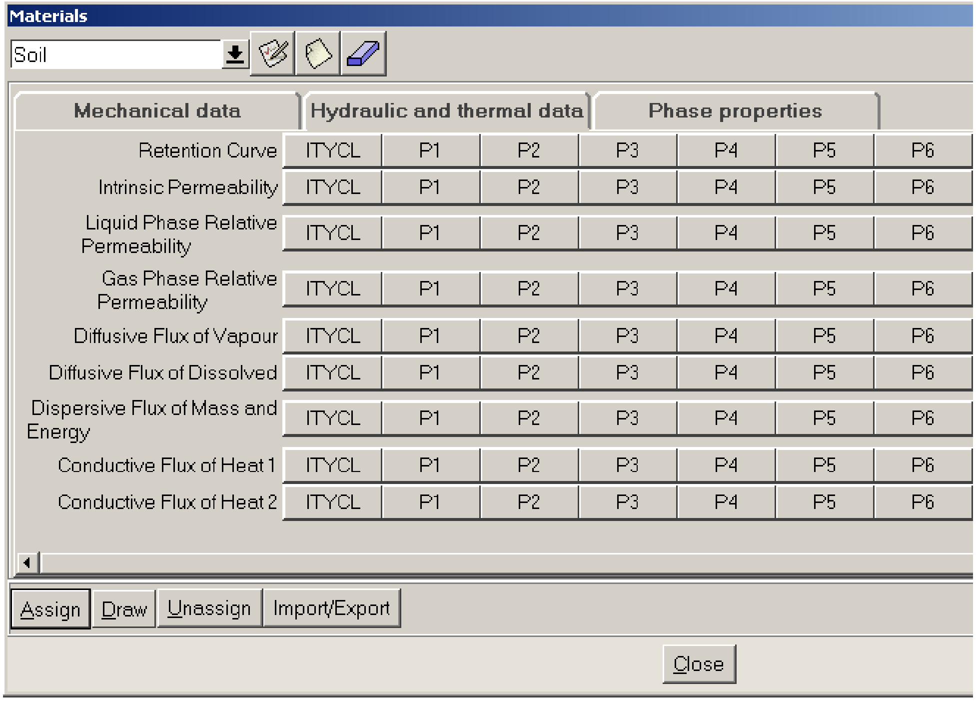
☐ Energy balance (unknown temperature)

Constant Temp[MPa] 20

Vapour into gas phase: Not allowed

☐ Mass balance of conservative species (unknown solute concentration w)

Fig. 1: Windows defining the system of equations to use.



Retention Curve	ITYCL	P1	P2	P3	P4	P5	P6
Intrinsic Permeability	ITYCL	P1	P2	P3	P4	P5	P6
Liquid Phase Relative Permeability	ITYCL	P1	P2	P3	P4	P5	P6
Gas Phase Relative Permeability	ITYCL	P1	P2	P3	P4	P5	P6
Diffusive Flux of Vapour	ITYCL	P1	P2	P3	P4	P5	P6
Diffusive Flux of Dissolved	ITYCL	P1	P2	P3	P4	P5	P6
Dispersive Flux of Mass and Energy	ITYCL	P1	P2	P3	P4	P5	P6
Conductive Flux of Heat 1	ITYCL	P1	P2	P3	P4	P5	P6
Conductive Flux of Heat 2	ITYCL	P1	P2	P3	P4	P5	P6

Fig. 2: Window defining the hydraulic parameters of the materials.

EXAMPLE OF APPLICATION

One of the applications performed with Code_Bright/GiD consisted in the three-dimensional thermo-mechanical simulation of an *in situ* test currently in progress in the Asse salt mine – Germany (Droste *et al.* 1996, see Fig. 3). The TSS (Thermal Simulation of Drift Emplacement) test aims at simulating the behaviour of a repository in rock salt. It consists of two parallel tunnels (length=70 m) separated 14.8 m and backfilled with crushed salt. Monitoring instrumentation was installed in the backfill and the host formation. Three heaters (length of 5.5 m, diameter of 1.5 m and thermal power of 6.4 kW) were emplaced in each tunnel to represent the thermal load of the radioactive waste canisters.

The finite element mesh is shown in Fig. 4a. Field measurements indicated that the problem can be considered symmetric with respect to the plane between drift A and drift B. Consequently, the domain modelled includes the cross section of only one tunnel (with three heaters) and part of the confining host rock. Initial and boundary conditions have been obtained from published reports by GRS (Droste et al 1996).

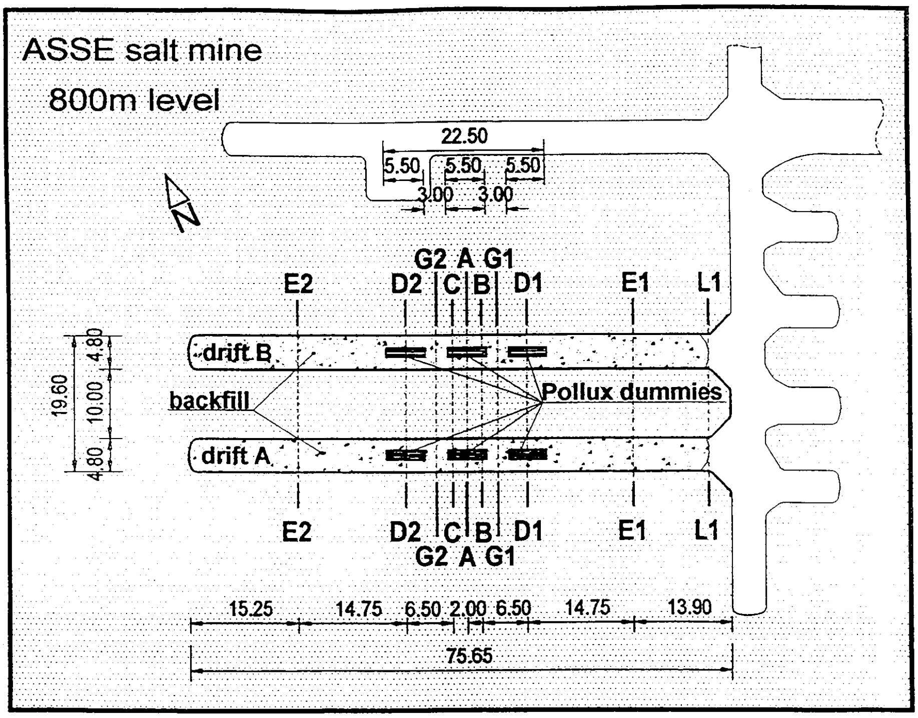
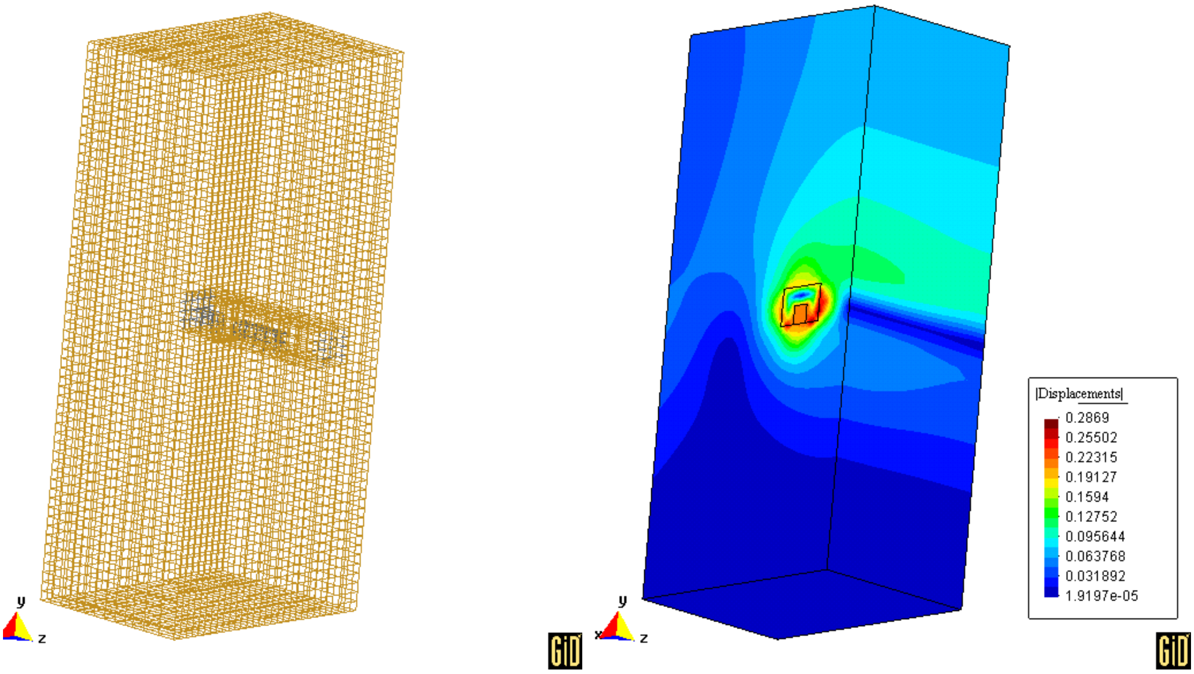


Figure 3: General view of the TSS test field on the 800 m level.

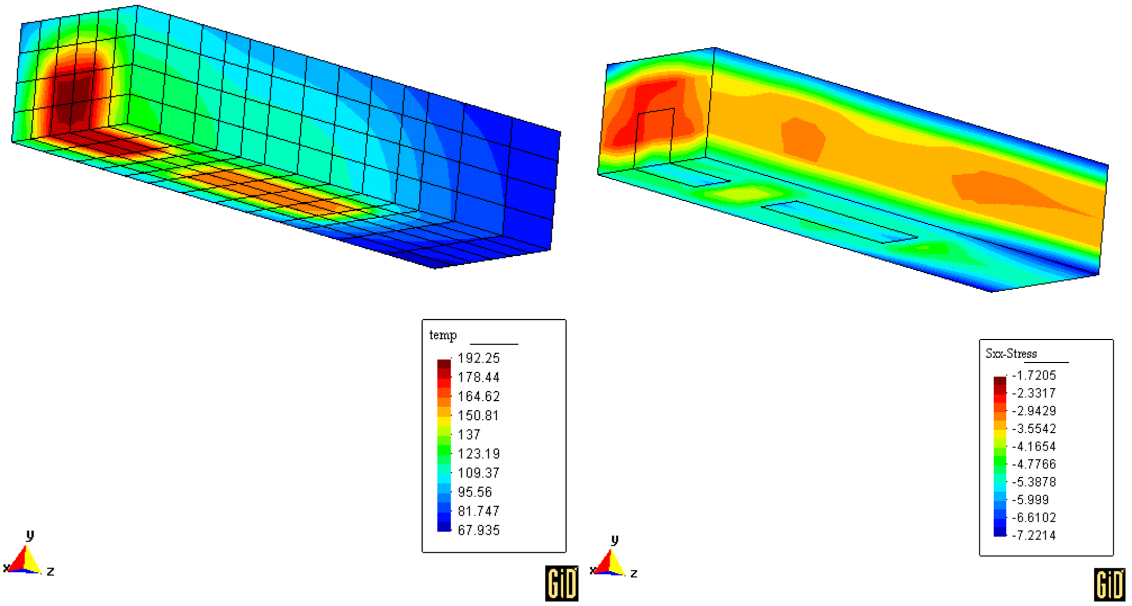
The simulation is achieved by solving stress equilibrium and heat transfer equations. A porosity dependent thermoviscoplastic behaviour, where the strains depend on the stresses through a power law, is considered for the salt (Olivella 1995). Strong couplings exist due to the dependency of the heat capacity on porosity, the dependency of the viscous coefficients on temperature and the dependency of the thermal conductivity on temperature and porosity. The model considers moreover two deformation mechanisms: the dislocation creep (DC) due to solid (salt) grains deformation and the fluid assisted diffusional transfer (FADT) due to dissolution/diffusion/precipitation of salt at the pore scale. Finally, stresses changes as a consequence of rock and backfill thermal expansion.

Outputs of displacements, temperature and stresses are shown in Fig. 4b, 5a and 5b. The results shown that the behaviour of an *in situ* test simulating a repository in a salt mine can be properly modelled.



a) b)

Fig. 4: a) Mesh and b) output of displacements



a) b)

Fig. 5: Output of a) temperature, and b) stresses, inside the buffer.

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