Manual of CVFEM_ice

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1-Grid Set-up

One of the requirements of this particular model is that the finite element shape has to be a square, and the domain shape has to be a rectangle. The users can modify the dimension of the domain by changing the variables "xdim" and "ydim" at Line 44 and Line 45, respectively. The users can also update the number of nodal columns as well as the number of nodal rows by changing the variables "cols" and "rows" at Line 47 and Line 48, respectively. The half-length of the element ($DY = \frac{ydim}{rows-1}$) and the half-width of the element ($DX = \frac{xdim}{cols-1}$) should be the same in order to satisfy the "square element" requirement.

2-Input Parameters

The Young's modulus (E) and Poisson's ratio (nu) could be changed at Line 285 and Line 286, respectively. The code is written for a plane stress problem but could be switched to a plane strain problem (which is the case in Zhang et al. (2018)) just by turning on the commands at Line 290 and Line 291, respectively.

The transient nature of the geomechanical model is manifested in the evolving stress boundary condition at the top of the domain. The value of "icenode" controls the number of columns at the surface and will be used to populate the "xls" vector later. It worth noticing that the value of the "icenode" has to be the same as that of "cols". The users can vary the "ntime" and "delt" to change the number of time steps and the time step size. The product of "ntime" multiplied by "delt" is the total simulation time of ONE glacial cycle. The four corner points of the trapezoid shape ice sheet evolution function are listed as "delt0", "delt1", "delt2", and "delt3" (refer to Zhang et al. (2018) for details). The specified lithosphere properties will be later on used in the solution to the beam bending equation to solve for the specified displacement at the bottom of the lithosphere domain.

These parameter setups are outside the main time loop.

3-Main Time Loop

3-1 Ice sheet model

The main time loop starts at Line 458, and we first calculate how the ice sheet thickness at the ice sheet divide (Ht) and the ice sheet length (Lt) evolve through time based on the ice sheet evolution function. We then keep track of how ice sheet thickness varies through time at each individual column using the vector “nu_i”, which will later on be used in both the computation of displacement at the bottom and the computation of the specified stress on the top.

3-2 Calculation of specified displacement boundary at the bottom

We solve for the displacement (“wflx”) using the analytical solution to a 1-dimensional beam bending equation from Line 533 to Line 562 (see solutions and equations in the supplemental materials of Zhang et al. (2018) for details). Then the “wflx” variable is read in the subroutine “asthen_viscous” (included in the package) to calculate the position of the lithosphere bottom with viscous mantle flow taken into account. The subroutine “asthen_viscous” solves the 1-dimensional diffusion equation numerically using a finite difference scheme (see supplemental materials of Zhang et al. (2018) for details).

3-3 Implementation of boundary conditions

We implemented boundary conditions from Line 586 to Line 648. The value of variable “nseg” determines which edge we are dealing with, with 1 being the bottom, 2 being the right, 3 being the top and 4 being the left. The bottom specified displacement boundary is implemented through the variable “dis_m” and the top specified stress boundary is imposed via the variable “nu_i”. The users are recommended to refer to Voller (2009) for details about how to set up boundary conditions for control volume finite element models.

3-4 Solver for displacement (ux, uy)

The iterative solver (Point-Jacobi) under relaxation scheme is implemented from Line 654 to Line 671. The users could increase both the variable “iter” and the variable “init” to enhance the simulation accuracy, but potentially at a cost of longer simulation time. For details of the iterative solver, the users are recommended to refer to the supplemental materials of Zhang et al. (2018).

3-5 Post processing for stress calculation

The post processing of calculating the disturbed stresses given the displacement starts from Line 701 and ends at Line 906. Two essential variables we generated are the source term “dsig_dt” and the failure term “fc”, which will drive the fluid flow in Rift2D and determine the failure envelope due to pure mechanical loading, respectively.

4 Output

Three additional subroutines are called at the end of the program. First, the subroutine “tecout_whole” will generate the Tecplot formatted file for the entire model domain. Secondly, the subroutine “tecout_temp” serves as a function to generate the temperature nodal variable “temp” by reading in the subsurface temperature profiles of each individual 1-dimensional column. At last, the subroutine “tecout_rift2d” will generate the Tecplot formatted file containing a series of nodal variables including “dsig_dt”, “fc” and “temp” for a subsection of the entire domain that is ready to be read in for the Rift2D package.

5-References

Voller, V. R. (2009). *Basic control volume finite element methods for fluids and solids* (Vol. 1). World Scientific.

Zhang, Y. P., Person, M., Voller, V., Cohen, D., McIntosh, J., and Grapenthin, R. (2018). Hydromechanical Impacts of Pleistocene Glaciations on Pore Fluid Pressure Evolution, Rock Failure, and Brine Migration within Sedimentary Basins and the Crystalline Basement, *Water Resources Research*, in press.