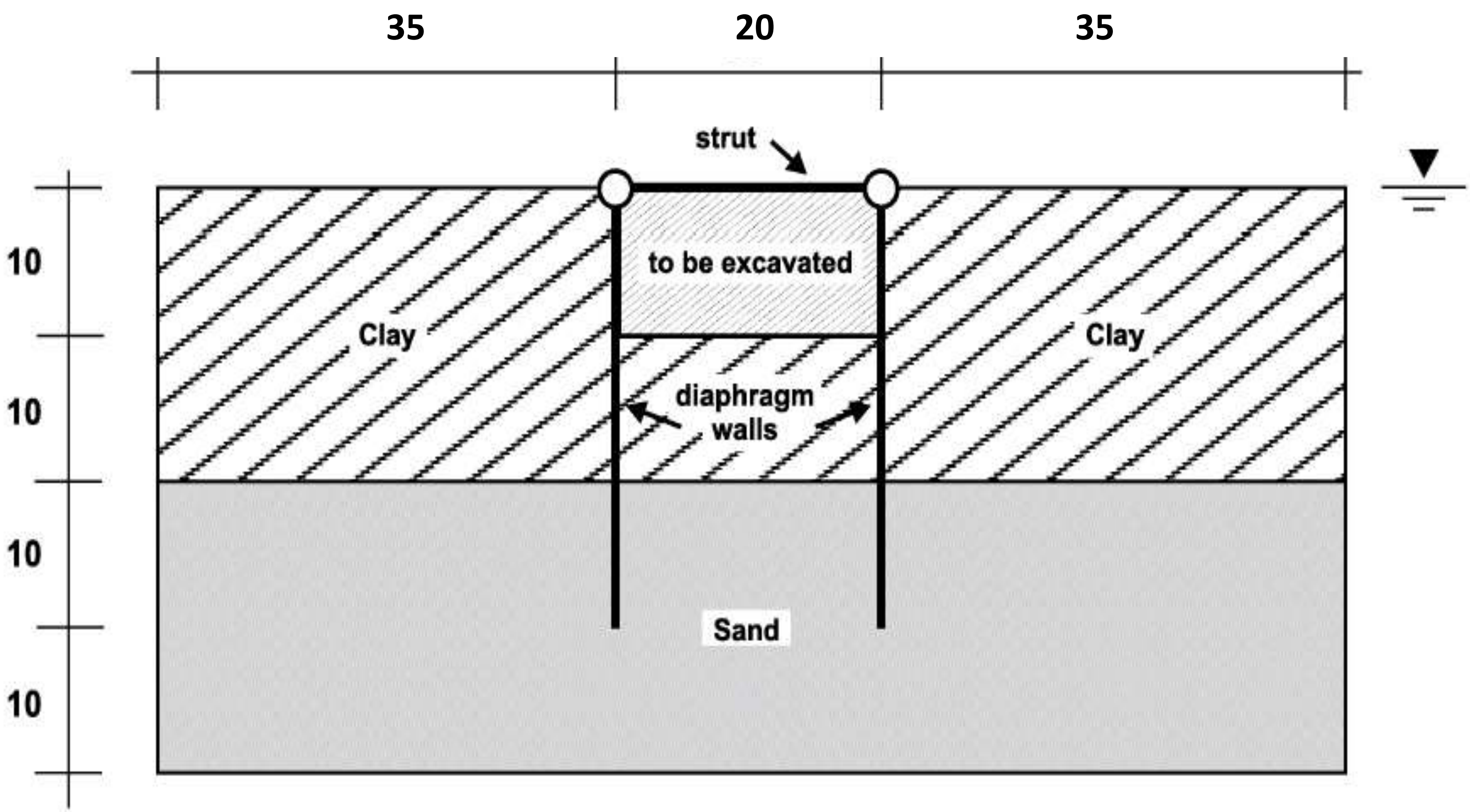
Example Application 13

Dewatered Construction of a Braced Excavation



Geometry for Braced Excavation

Drained Properties for Sand and Clay Layers – Mohr-Coulomb Model

	Sand layer	Clay layer
Dry density (kg/m^3)	1700	1600
Young's modulus (MPa)	40.0	10.0
Poisson's ratio	0.3	0.35
Cohesion (Pa)	0	0
Friction angle (degrees)	32	25
Dilation angle (degrees)	2	0

Drained Properties for Sand and Clay Layers – Cysoil Model

	Sand layer	Clay layer
Dry density (kg/m^3)	1700	1600
Ultimate friction angle (degrees)	32	25
Ultimate dilation angle (degrees)	2	0
Multiplier, *R*	2.333	5.667
G_{ref}	112.5	15.0
Reference pressure (MPa)	0.1	0.1
Poisson's ratio	0.2	0.2
Cohesion	0	0
Power, m_k	0.99	0.99
Failure ratio, R_f	0.9	0.9
Over consolidation ratio, *ocr*	1.0	1.0
Cap yield surface parameter, α	1.0	1.0
Calibration factor, β	1.0	1.0

Drained Properties for Sand and Clay Layers – PH Model

	Sand layer	Clay layer
Dry density (kg/m^3)	1700	1600
Friction angle (degrees)	32	25
Dilation angle (degrees)	2	0
E^{ref}_{50} (MPa)	22.5	6.0
E^{ref}_{ur} (MPa)	90.0	24.0
E^{ref}_{oed} (MPa)	30.0	4.0
Reference pressure (MPa)	0.1	0.1
Poisson’s ratio	0.2	0.2
Cohesion	0	0
Power, *m*	0.55	0.55
Failure ratio, R_f	0.9	0.9
Over consolidation ratio, *ocr*	1.0	1.0

Diaphragm Wall Properties

Equivalent thickness (m)	1.26
Density (kg/m^3)	2000
Young's modulus (GPa)	5.712
Poisson's ratio	0.2
Moment of inertia (m^4)	0.167

Strut Properties

Cross-sectional area (m^2)	1.0
Spacing (m)	2.0
Density (kg/m^3)	3000
Young's modulus (GPa)	4.0
Moment of inertia (m^4)	0.083

Wall/Interface Properties

Kn (Pa/m)	5.5e8
Ks (Pa/m)	5.5e8
Cohesion (Pa)	2500
Friction (deg)	12.5
Dilation	0

Fluid Flow Properties

Porosity	0.3
k (m^2/Pa-sec)	1e-10
Kw (GPa)	0.1
Density (kg/m^3)	1000

Modeling Procedure

Step 1 Generate the model grid and assign boundary conditions to represent the physical system.

Step 2 Assign the material model (Mohr-Coulomb, Cysoil or PH) and material properties. Solve for the initial equilibrium state prior to construction.

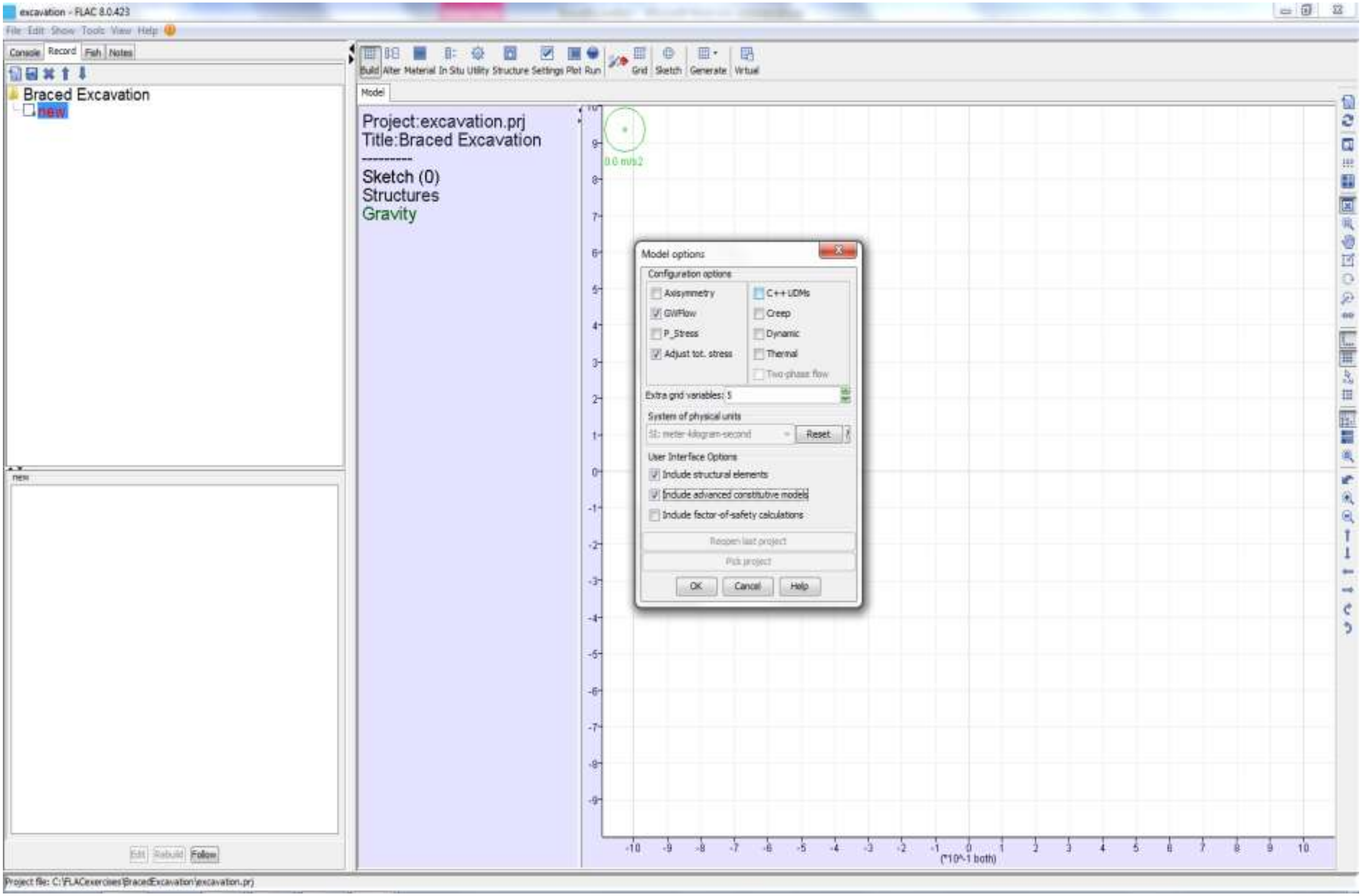
Step 3 Determine the initial in-situ state of the ground with the diaphragm wall installed.

Step 4 Lower the water level within the region to be excavated to a depth of 20 m below the ground surface.

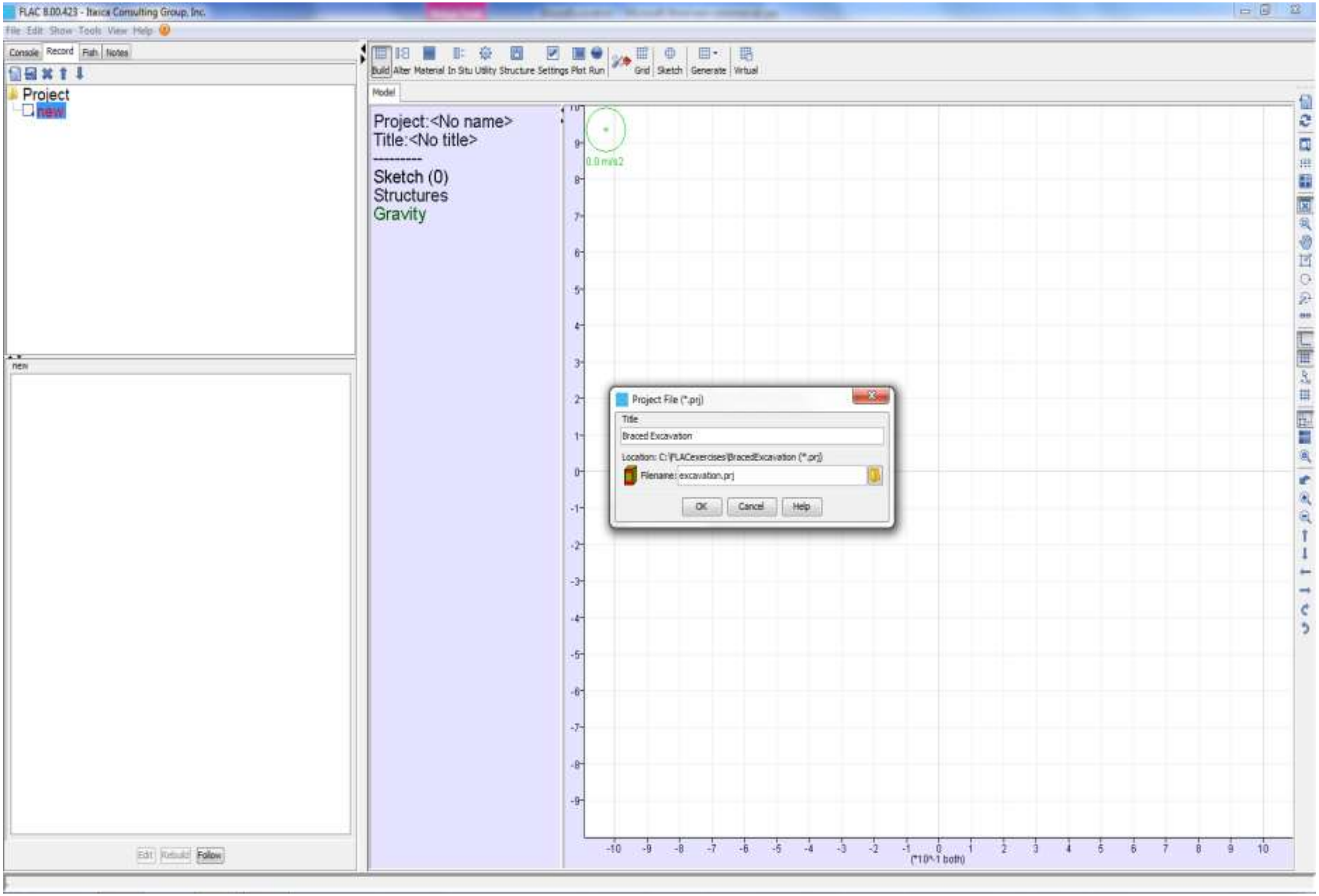
Step 5 Excavate to a depth of 2 m.

Step 6 Install the horizontal struts at the top of the wall, and then excavate to a depth of 10 m.

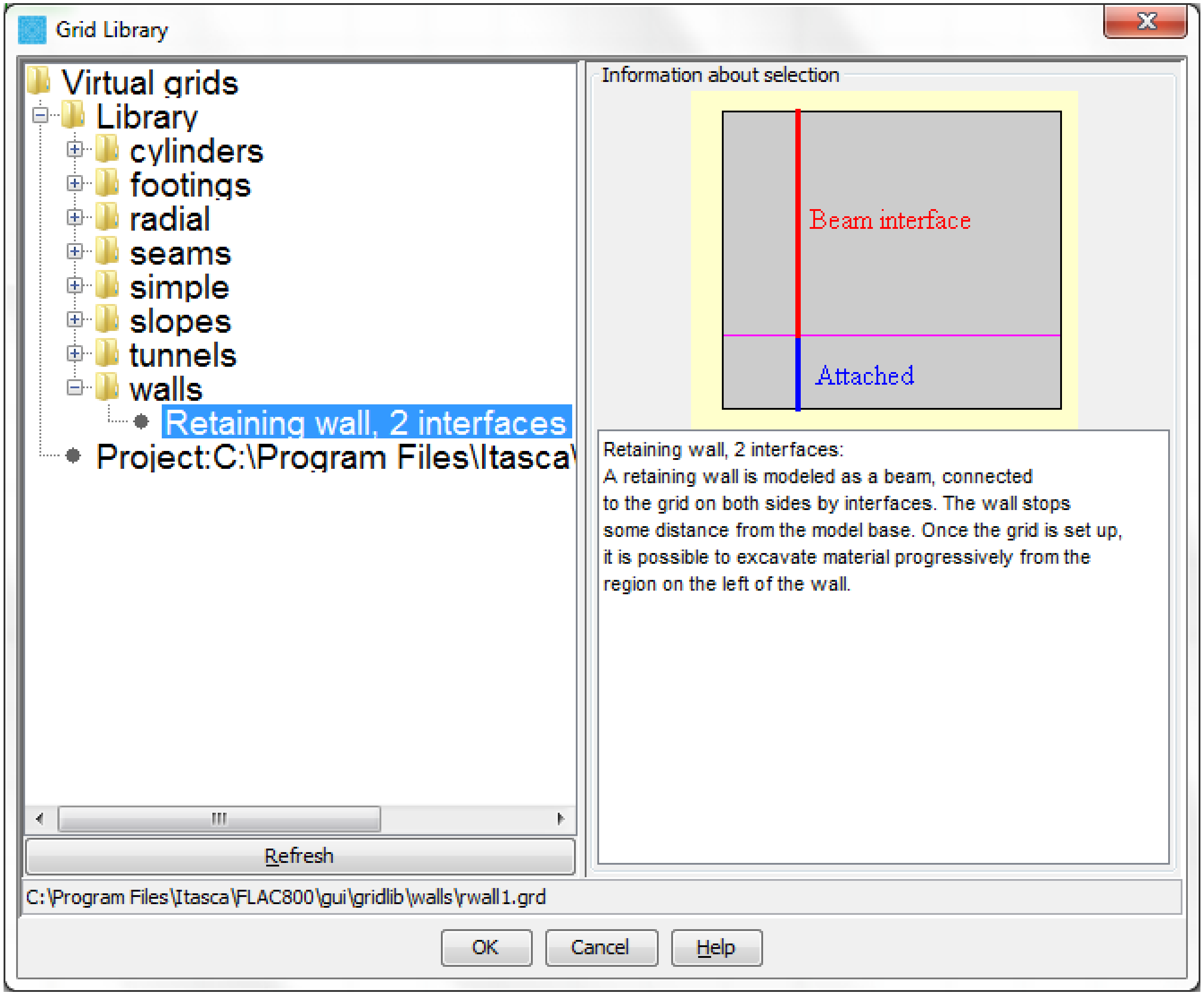
Step 7 Compare results for Mohr-Coulomb material, Cysoil material and PH material.



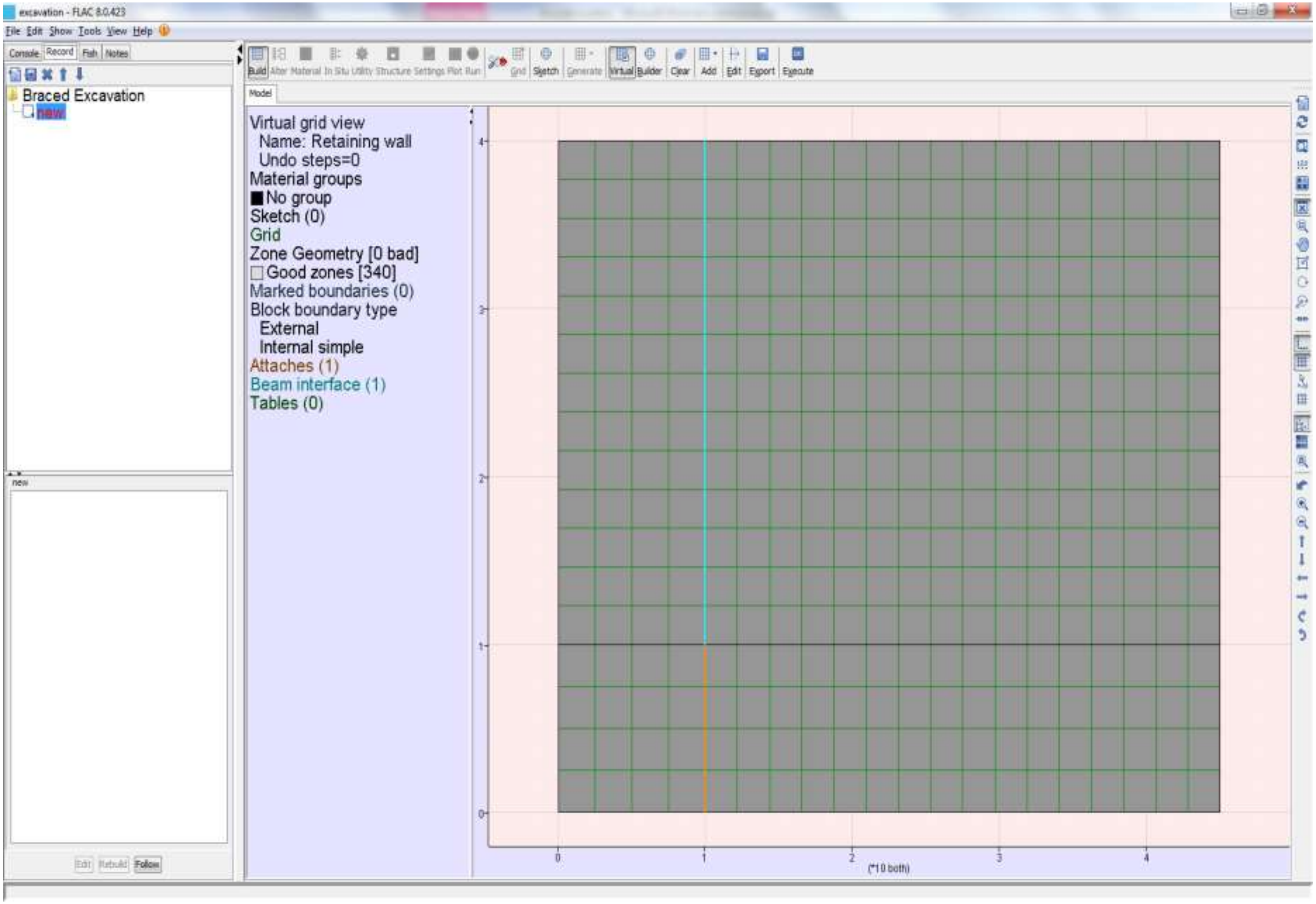
The [GWFlow] and [Adjust total stress] configuration options, 5 Extra grid variables, the [Include structural elements] and [Include advanced constitutive models] User Interface options will be used for this exercise.



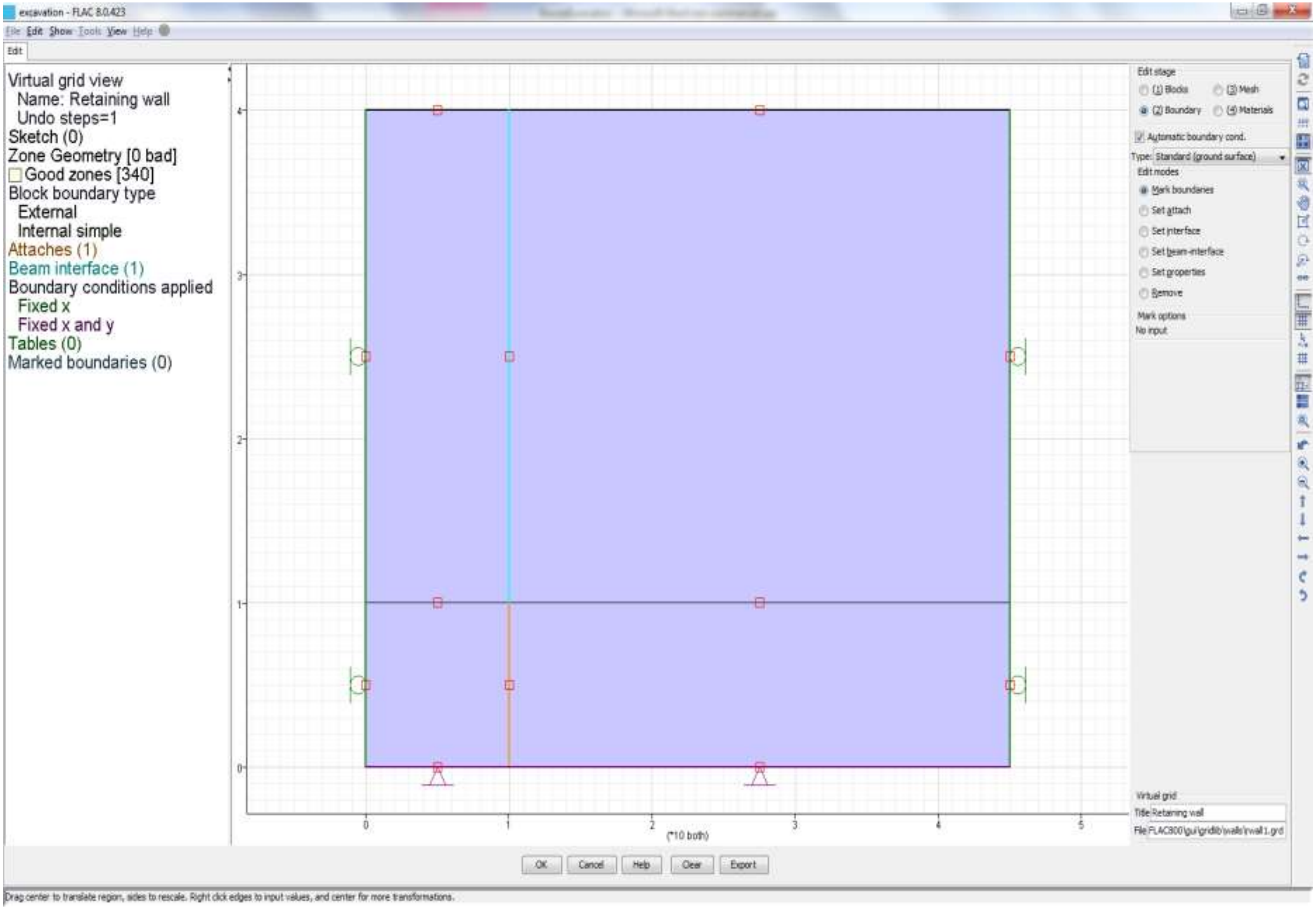
A project title is assigned, and a project file **excavation.prj** is created and stored in a working directory.



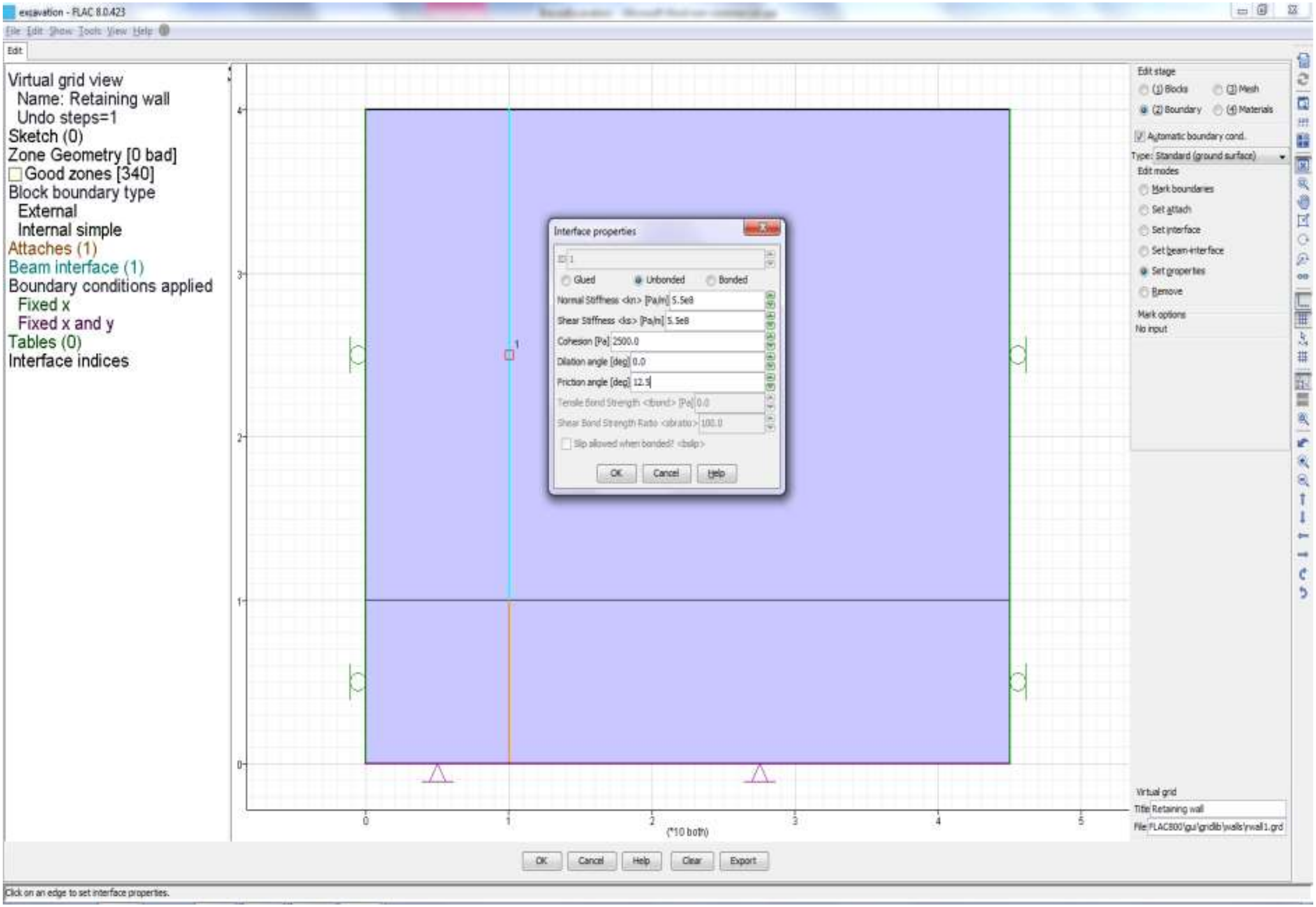
Step 1-1 Open the [Build]/[Generate]/[Library] tool and click on "Retaining wall, 2 interfaces" library item. (Note that half the problem is modeled. A line of symmetry is assumed through the center of the excavation.)



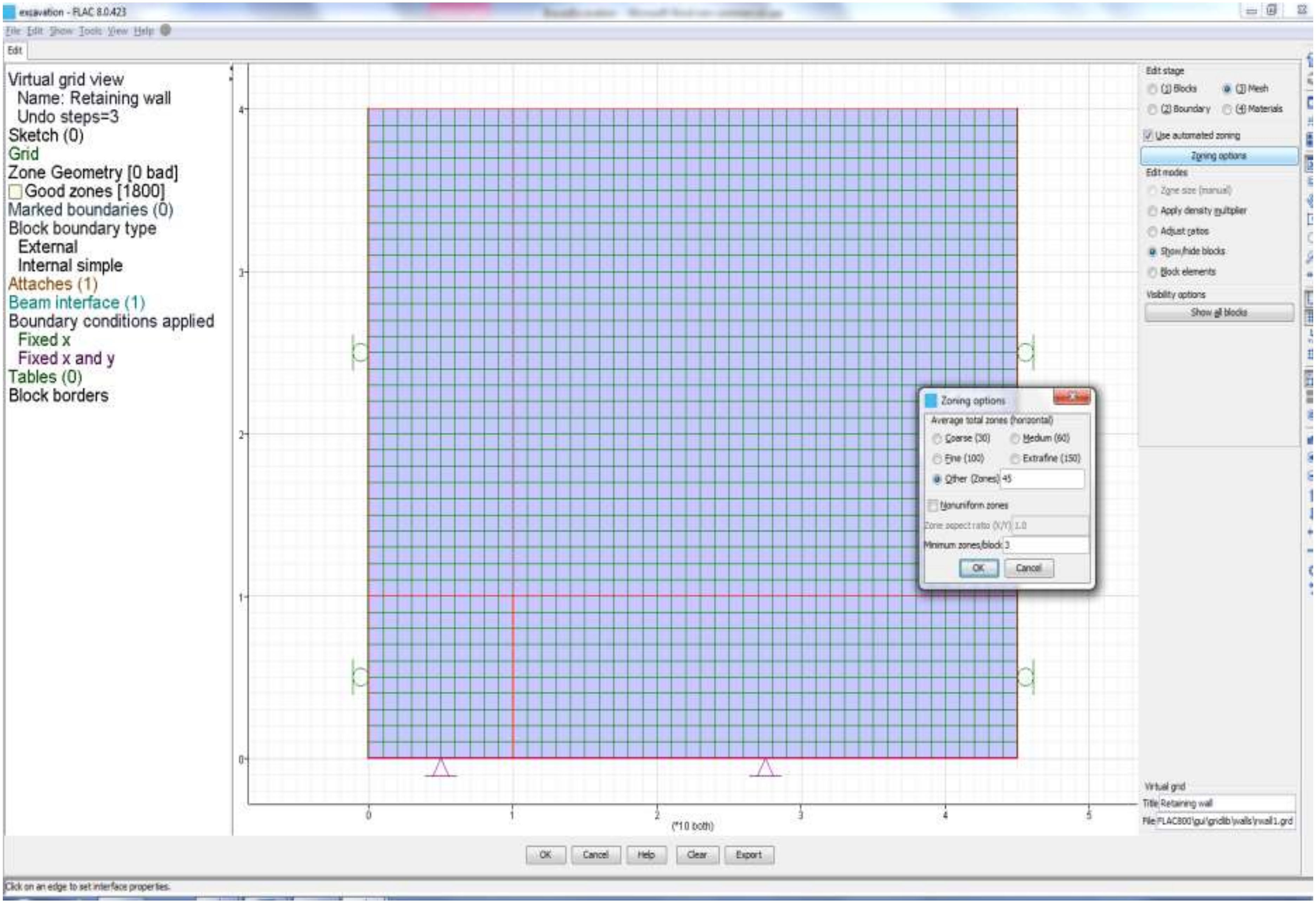
Step 1-2 Click [OK] and set the dimensions to 40m by 45m. The model virtual grid appears as shown above.



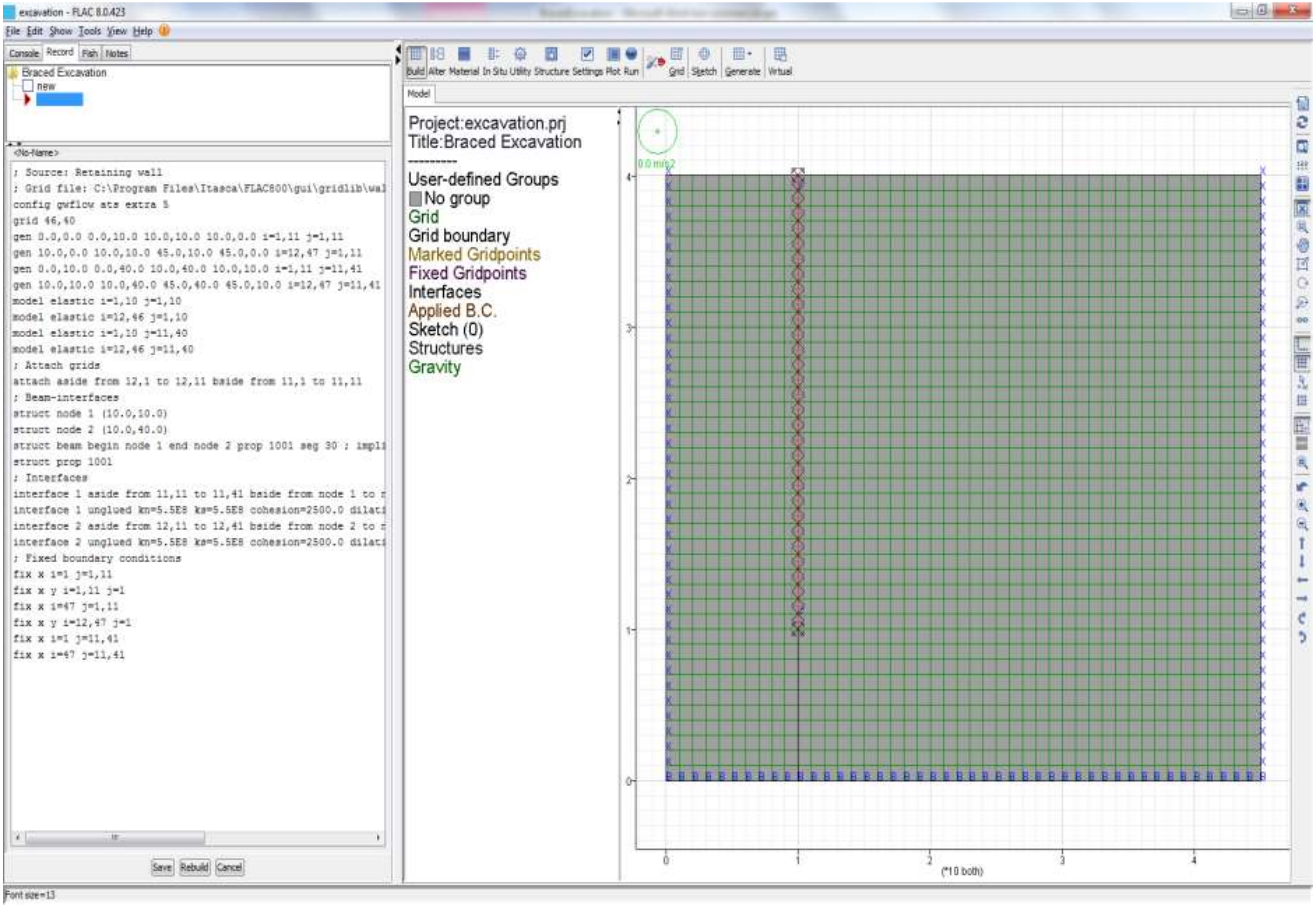
Step 1-3 In the [Edit] tool, set boundary conditions by checking [Automatic boundary cond.] in [Boundary] stage.



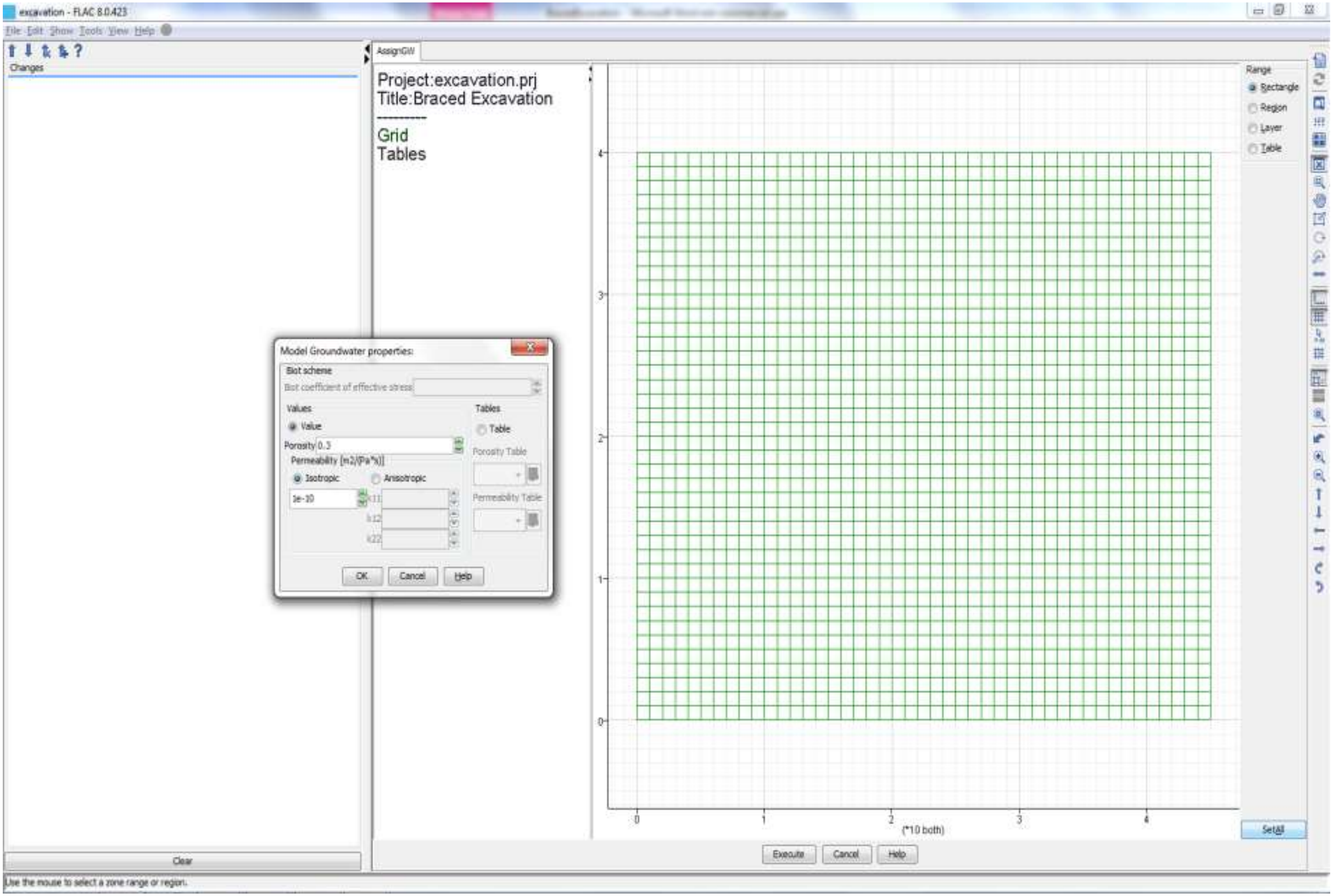
Step 1-4 Select [Set properties] mode to assign wall/interface properties.



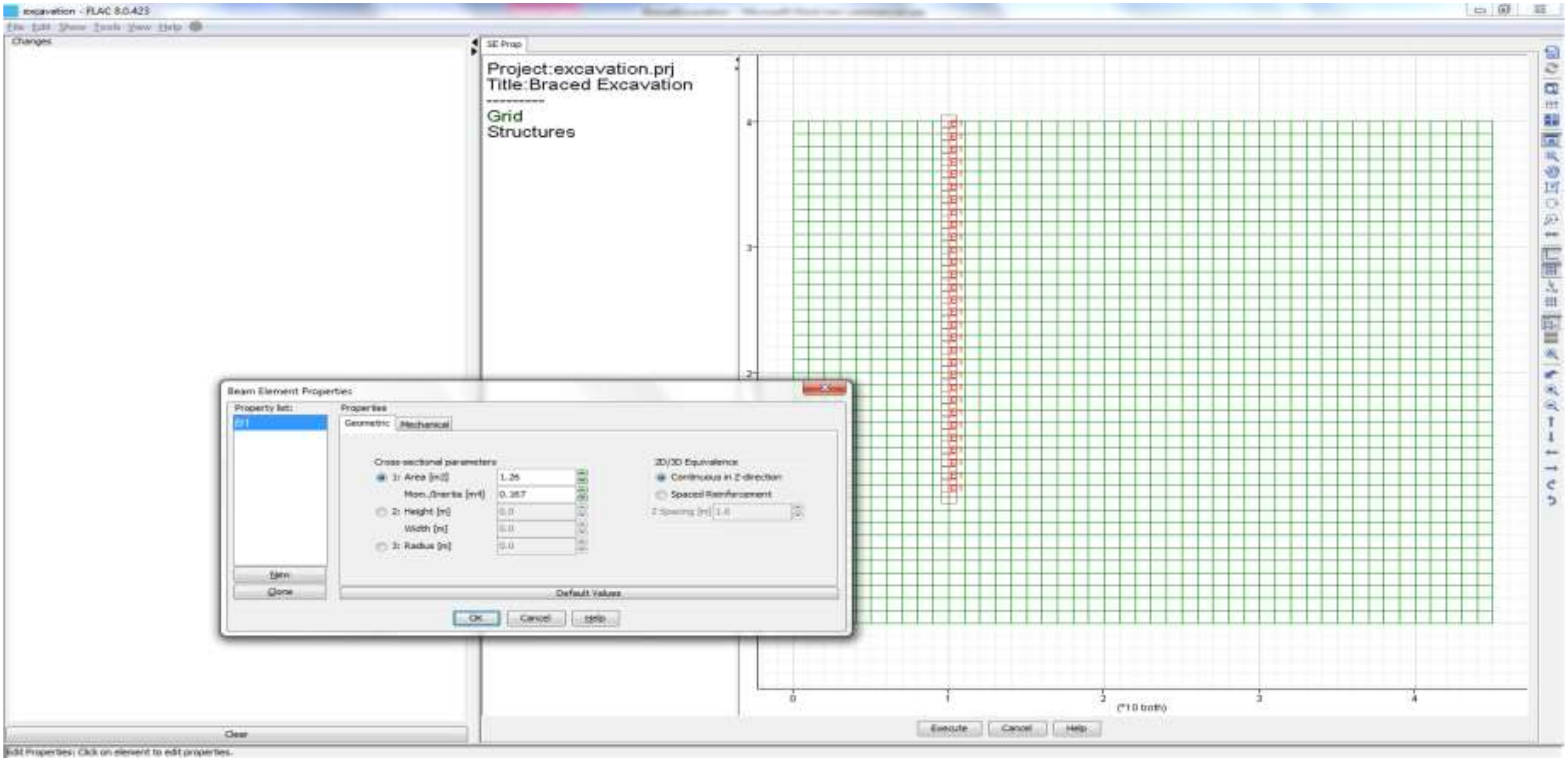
Step 1-5 Select [Use automated zoning] mode in the [Mesh] stage and input 45 zones in the horizontal direction.



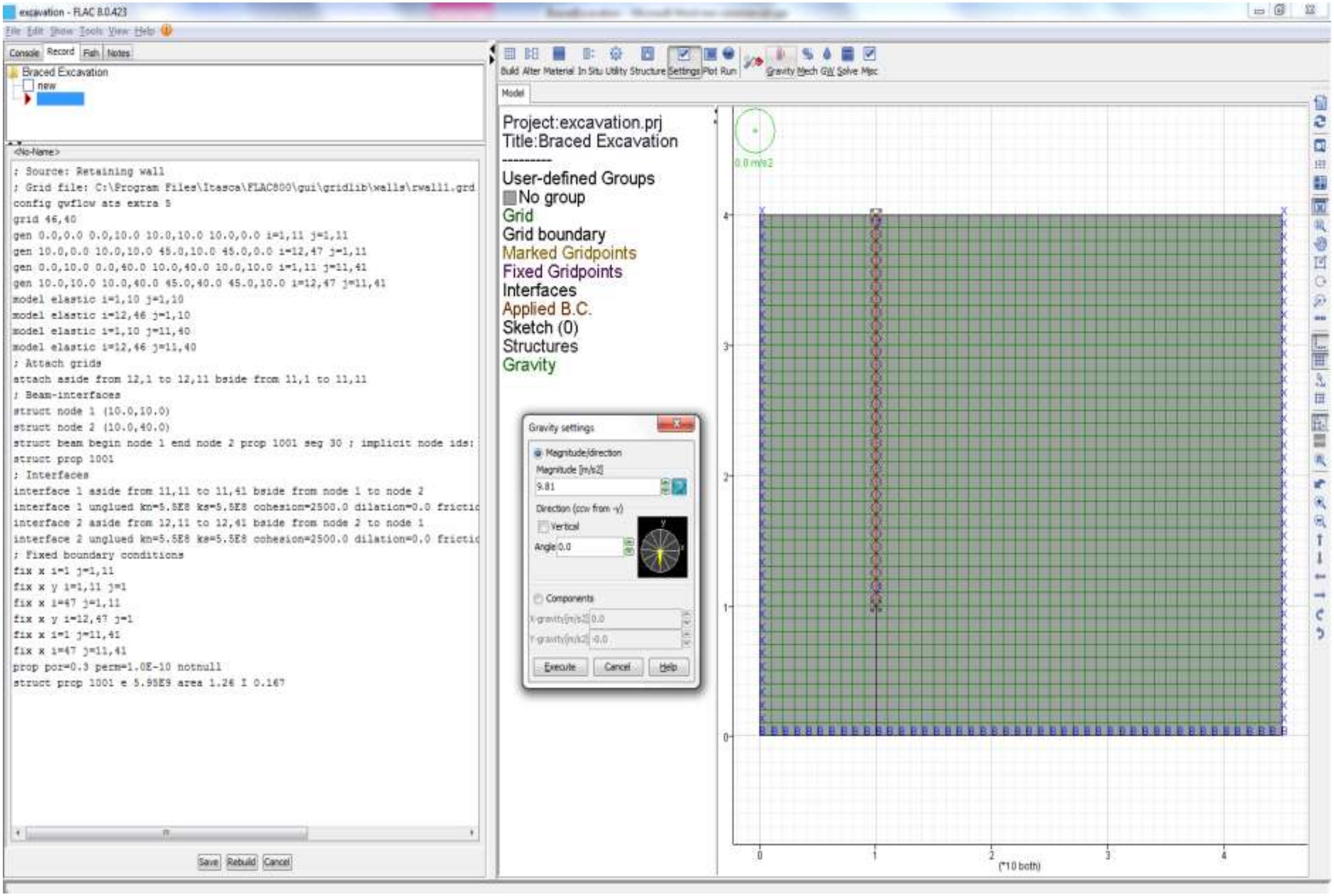
Step 1-6 Click [OK] to exit the [Edit] tool and then click on [Execute] to create commands and send to FLAC.



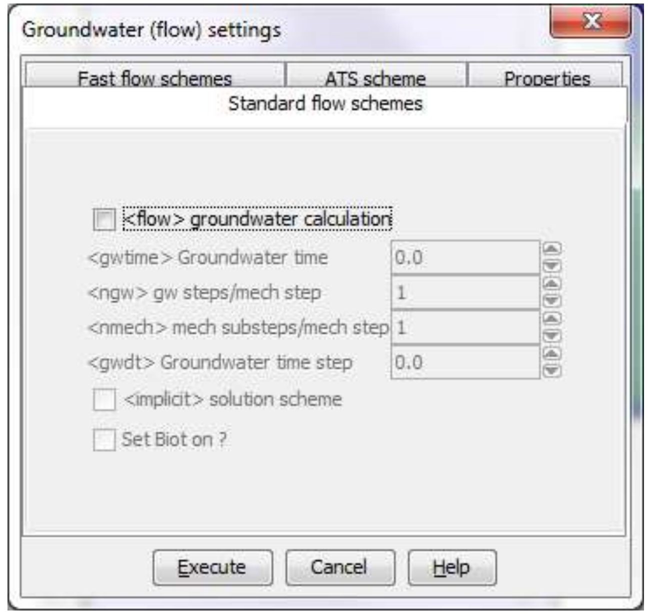
Step 1-7 Select the [Material]/[GWProp] tool to assign porosity and permeability properties for all the zones in the model.

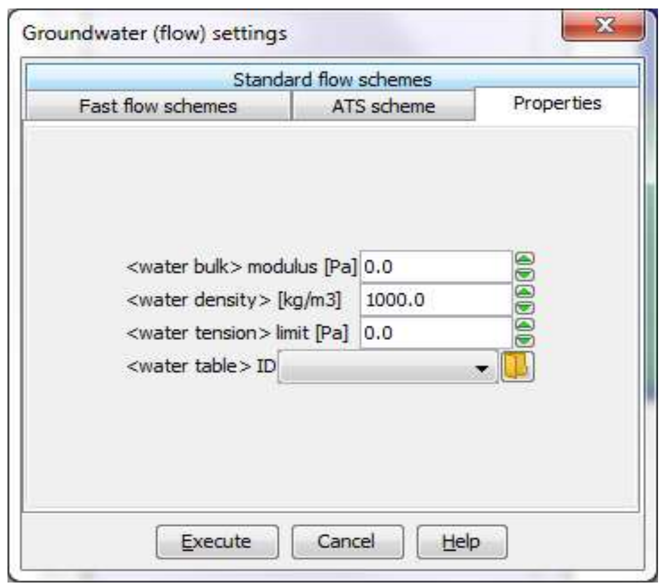


Step 1-8 Select the [Structure]/[SEProp] tool to assign properties for the diaphragm wall. (Young's modulus is changed to 5.95 GPA to covert from plane stress to plane strain for the continuous wall.)

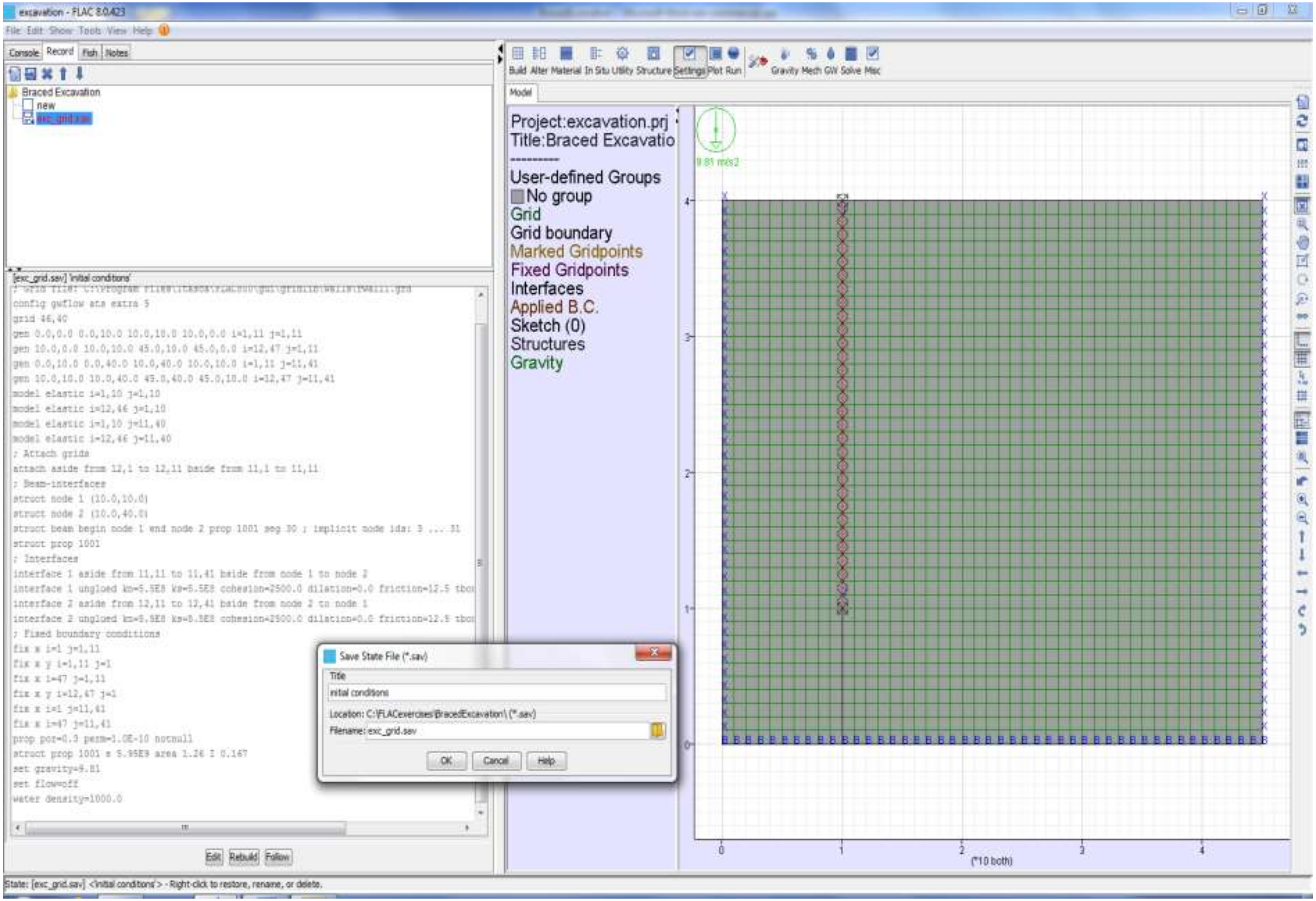


Step 1-9 Turn on gravity using the [Settings]/[Gravity] tool.

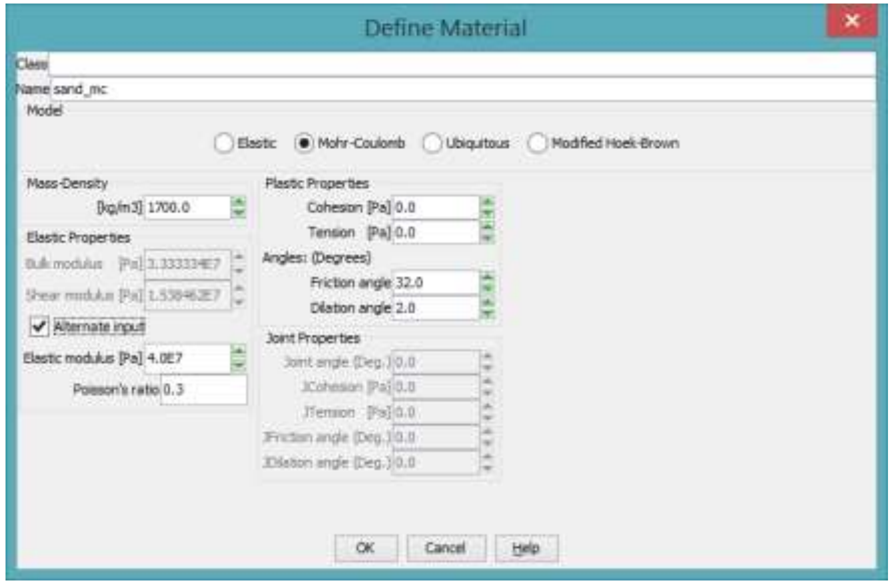


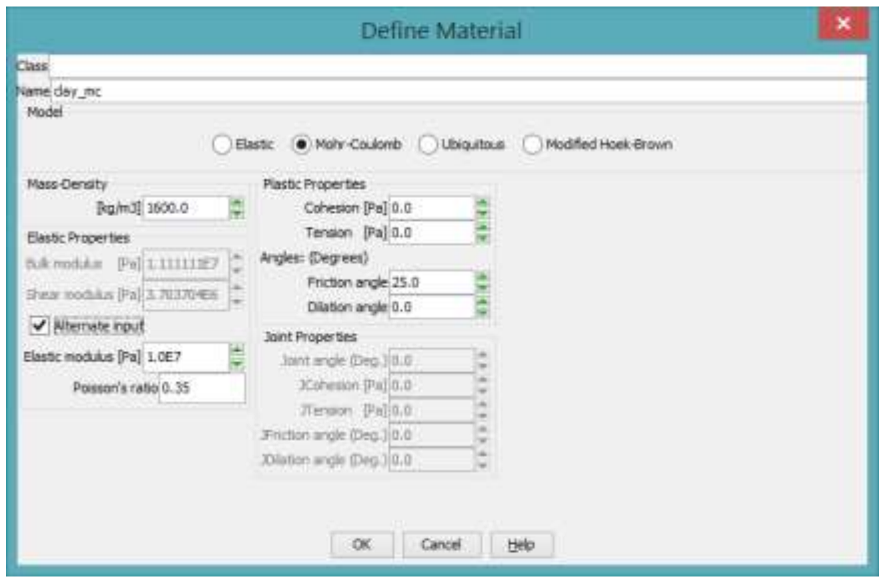


Step 1-10 Turn off groundwater flow and set water density to 1000 kg/m3 using the [Settings]/[GW] tool.

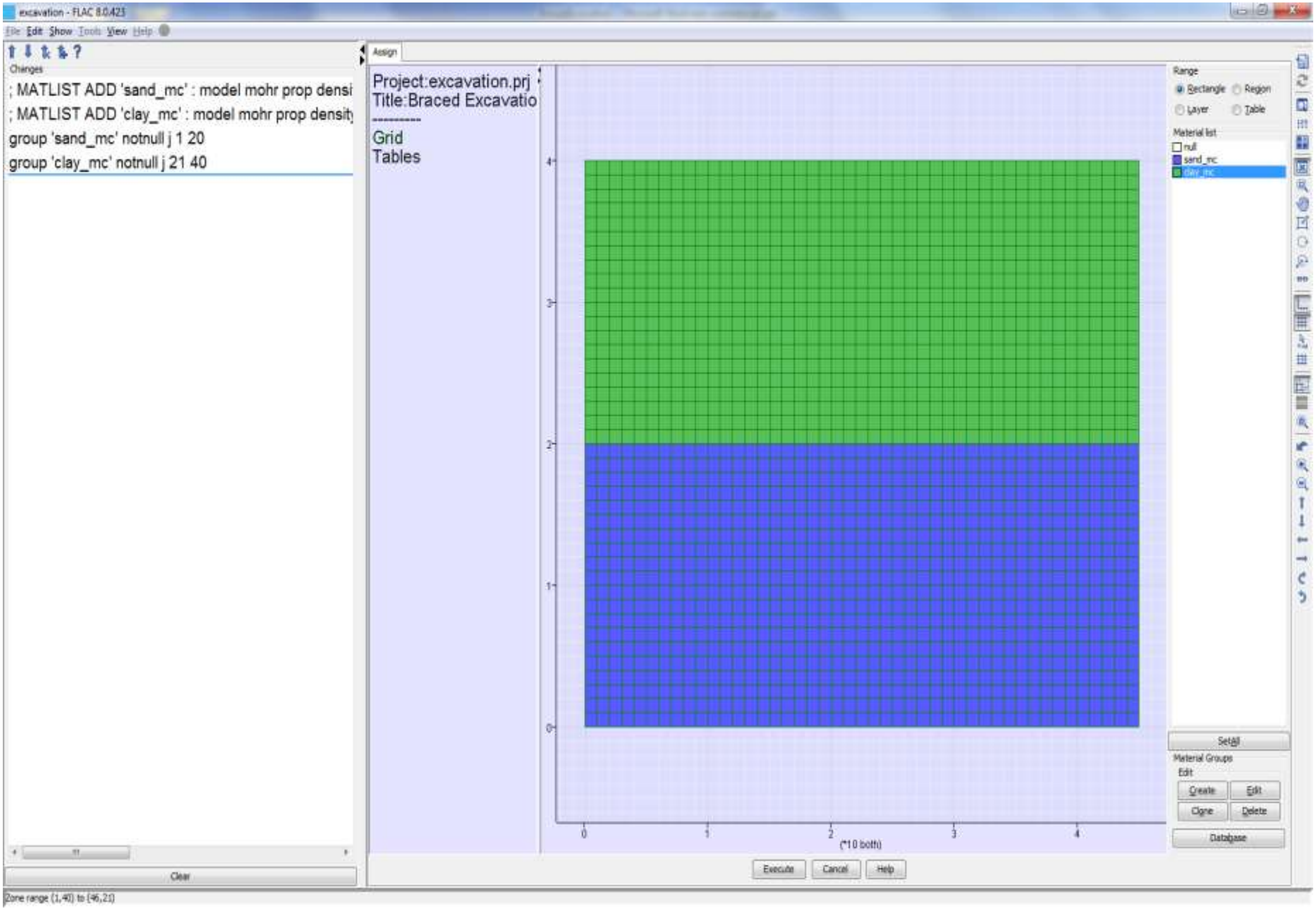


Step 1-11 Save the model state as exc_grid.sav.

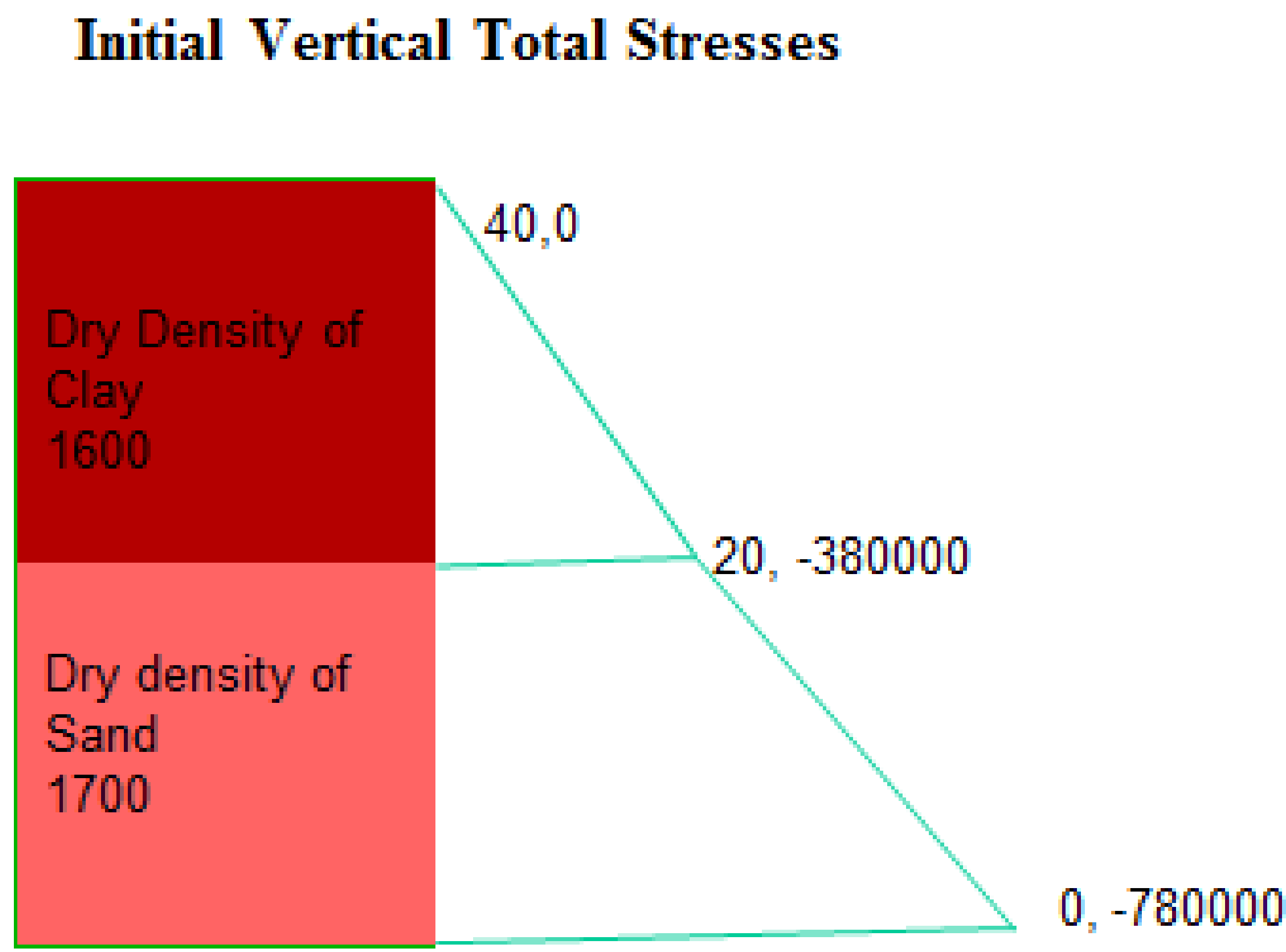




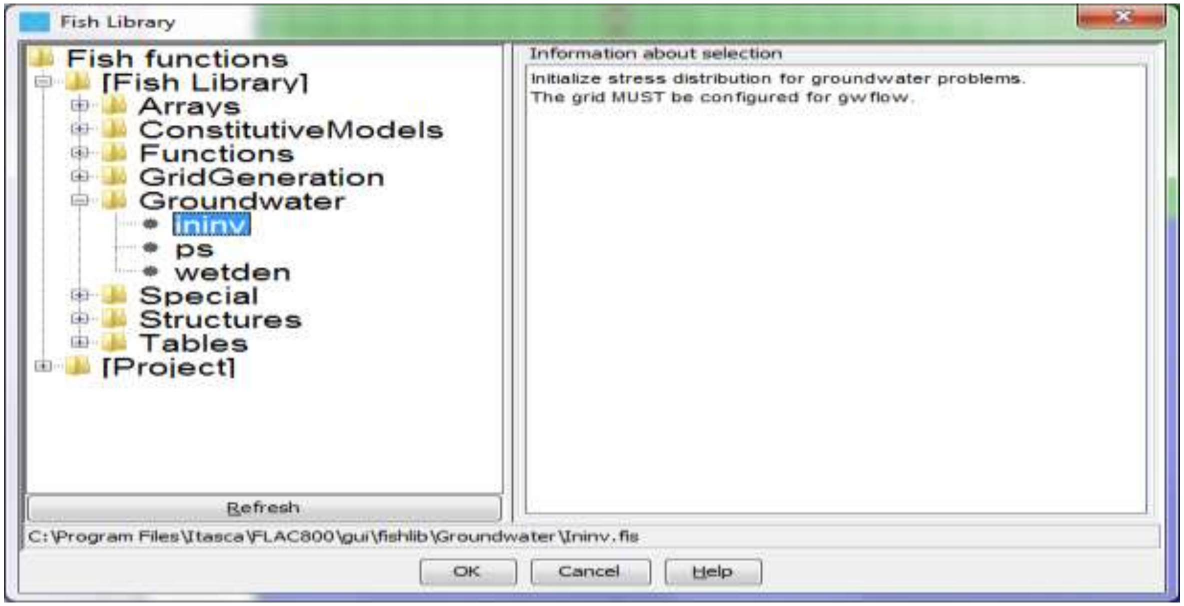
Step 2-1 In the [Material]/[Assign] tool, select [Set all] and [Create] to open the *Define Material* dialog and assign the Mohr-Coulomb properties for the sand and clay.



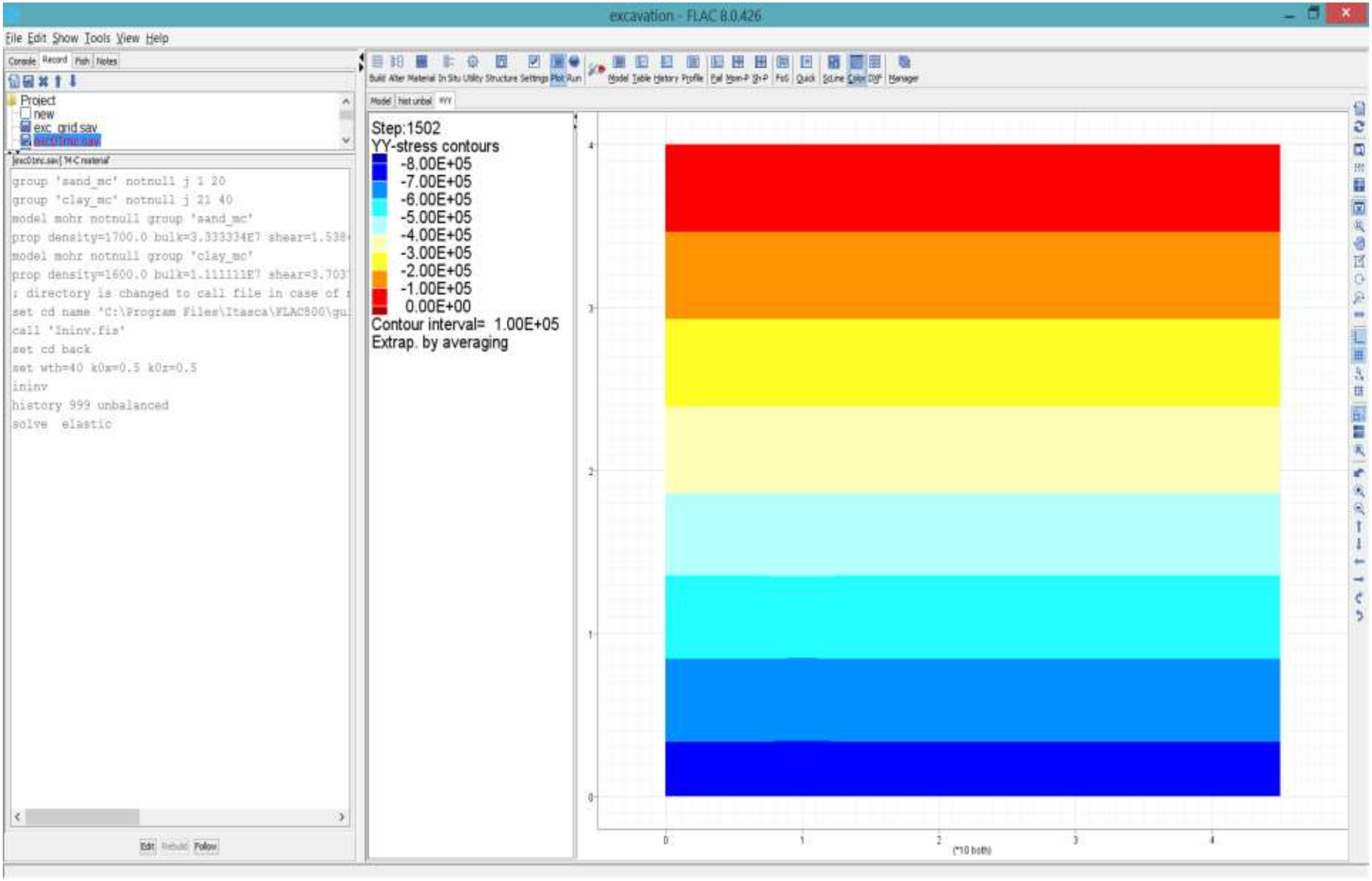
Step 2-2 Assign the sand material to the lower half of the model (j=1,20) and the clay material to the upper half (j=21,40).



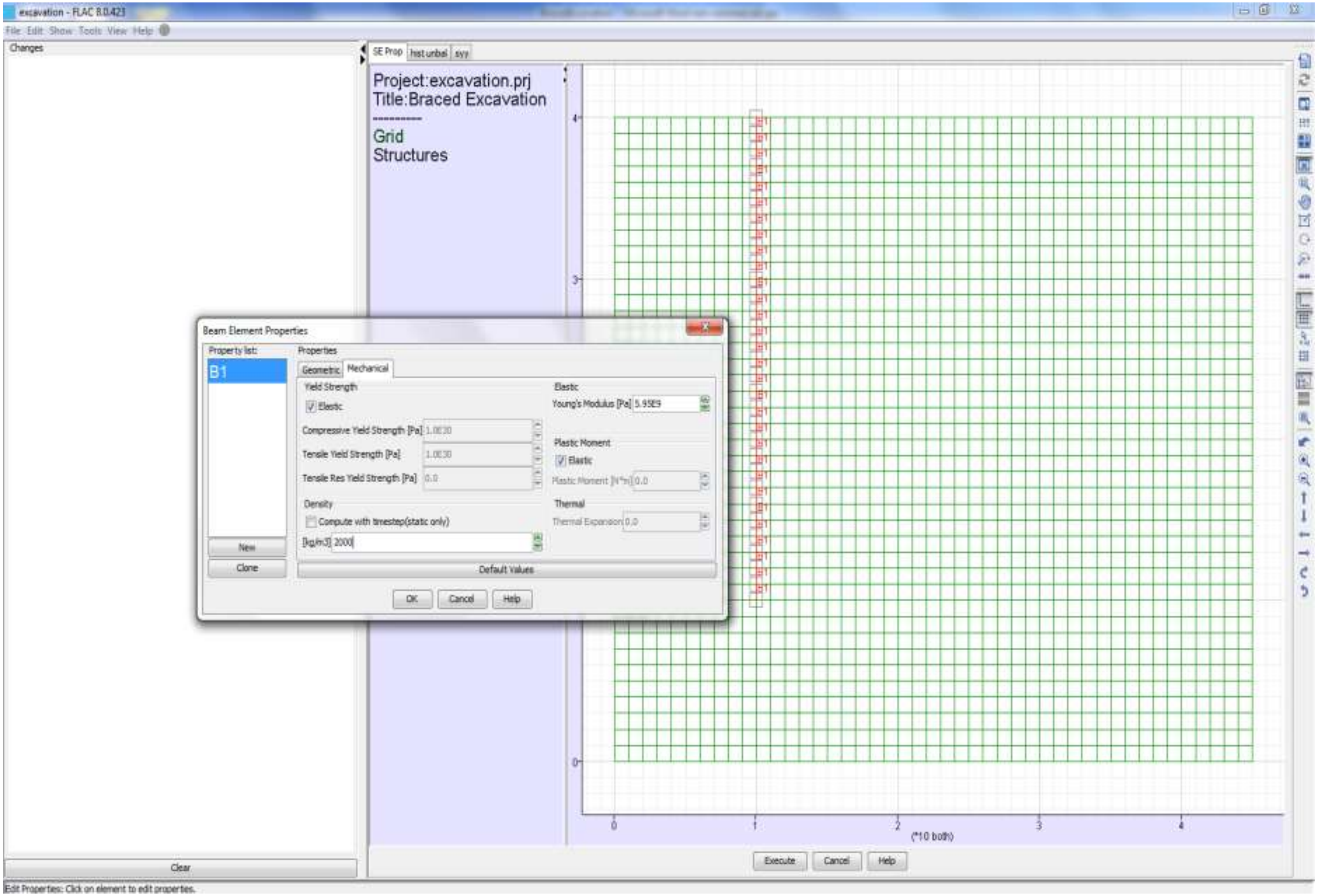
Step 2-3 FISH function ININV.FIS assigns pore pressure, total stress and effective stress distribution for horizontally layered stratigraphy. Input is water table location and effective horizontal to vertical stress ratios.



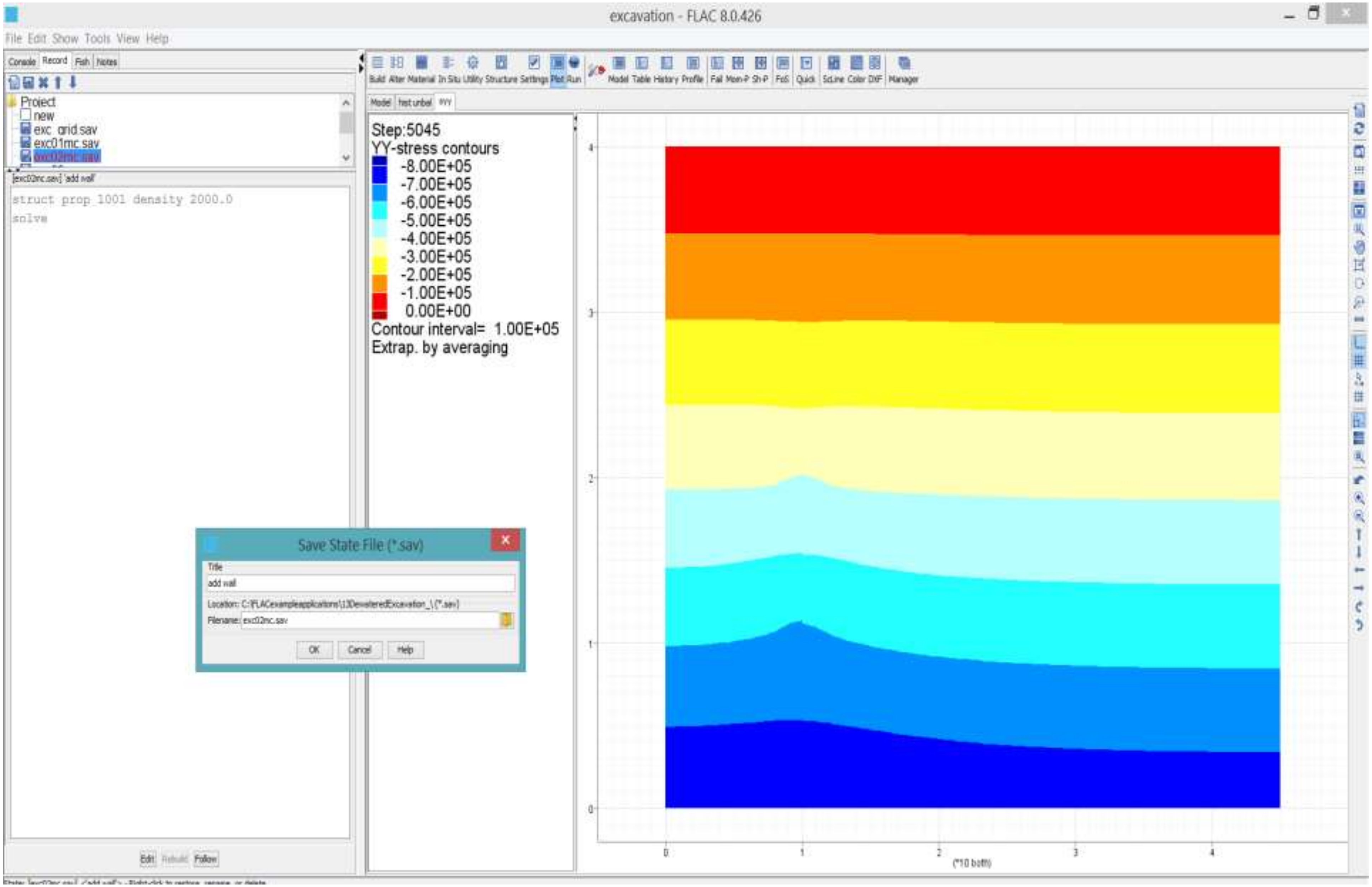
Step 2-4 ININV.FIS is accessed from the [Utility]/[FishLib] tool. Click on [Fish Library]/[Groundwater]/[ininv] to call in the function. Select [OK] and the Fish input dialog opens to enter the water table location and effective horizontal to vertical stress ratios



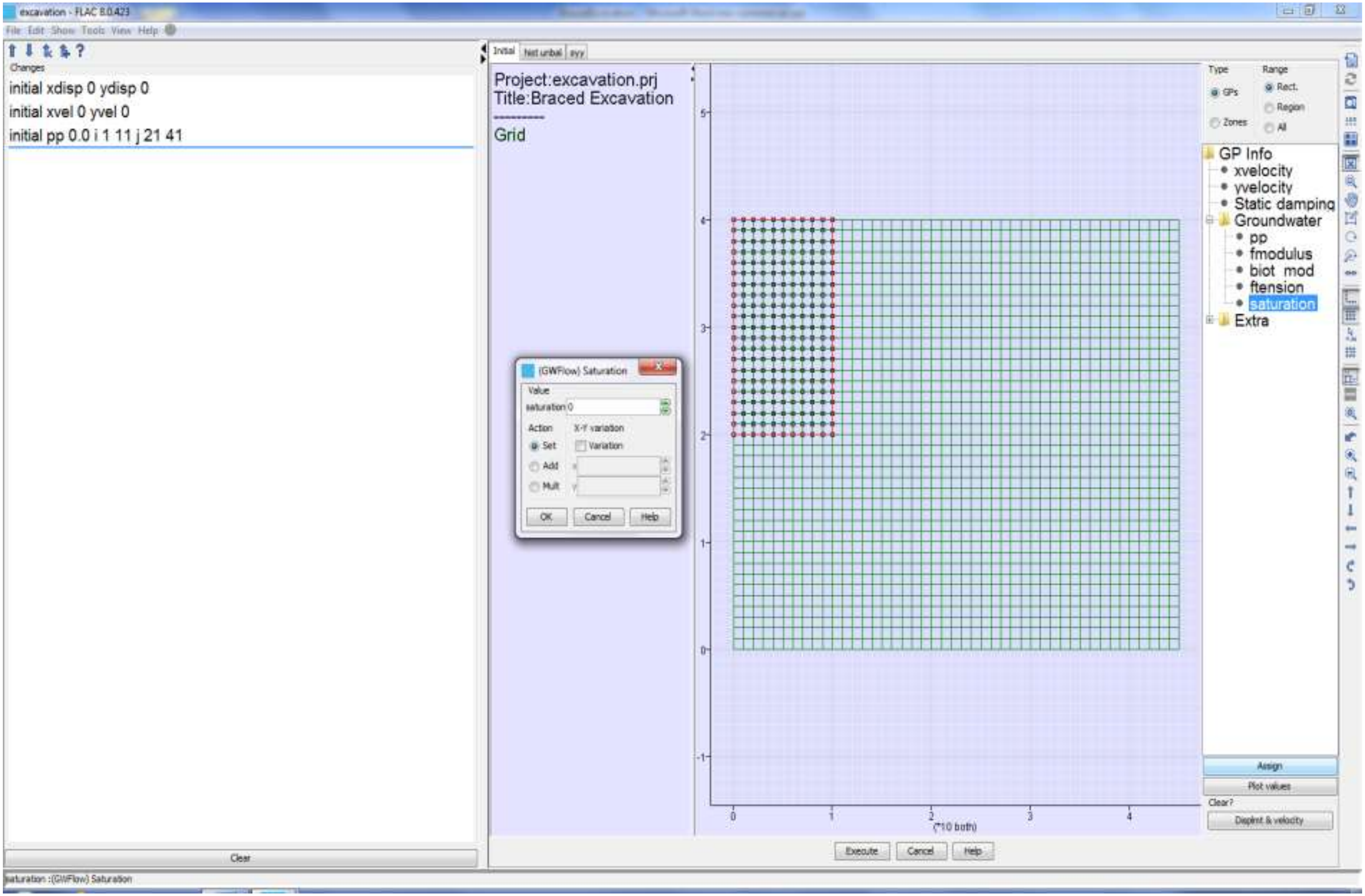
Step 2-5 Calculate the equilibrium state using [Run]/[Solve] and [Solve initial equilibrium as elastic model]. Plot total vertical stress contours using the [Plot]/[Model] tool. Save the state as exc_01mc.sav.



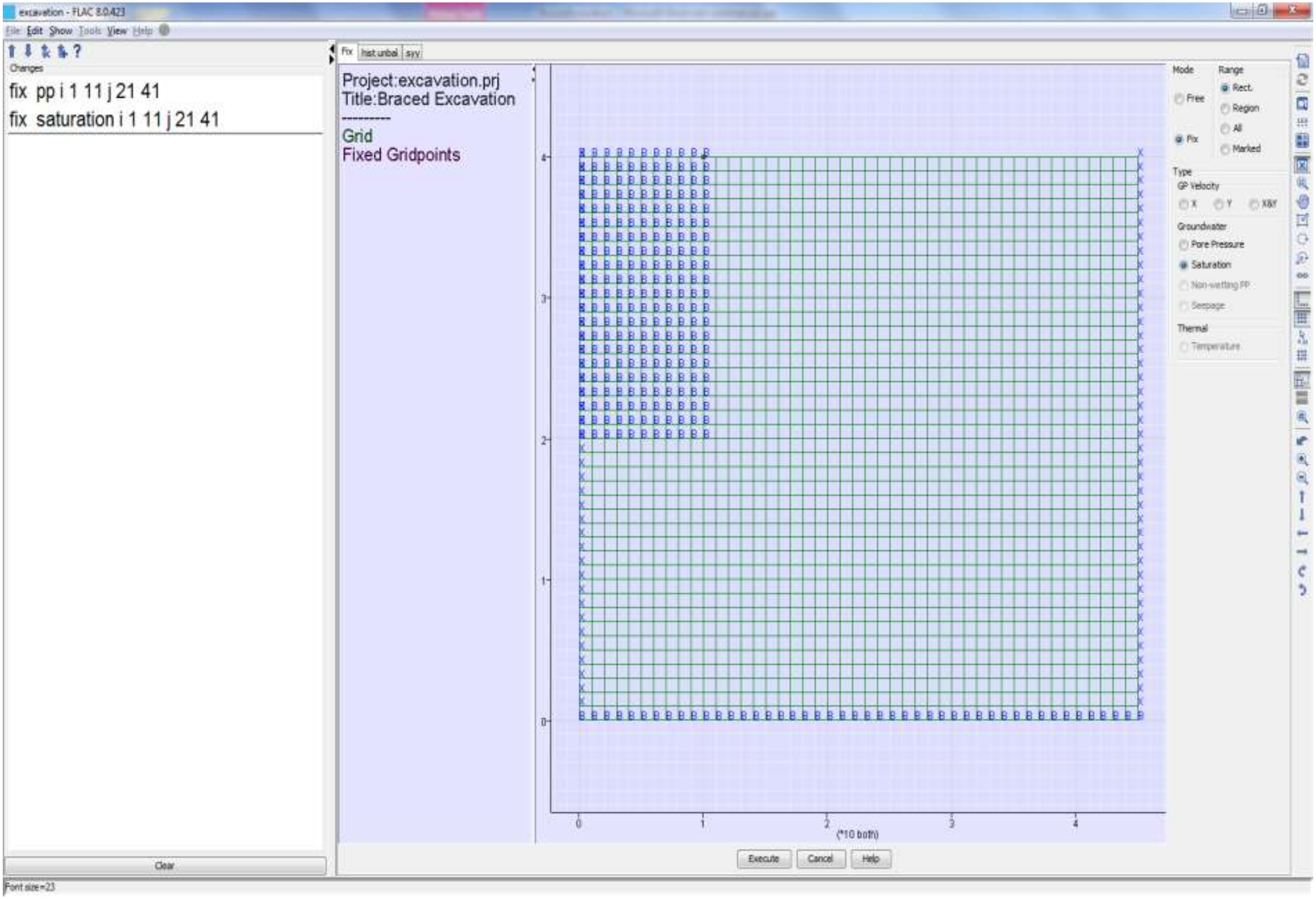
Step 3-1 The wall installation is performed by adding the density of the wall in the [Structure]/[SEprop] tool.



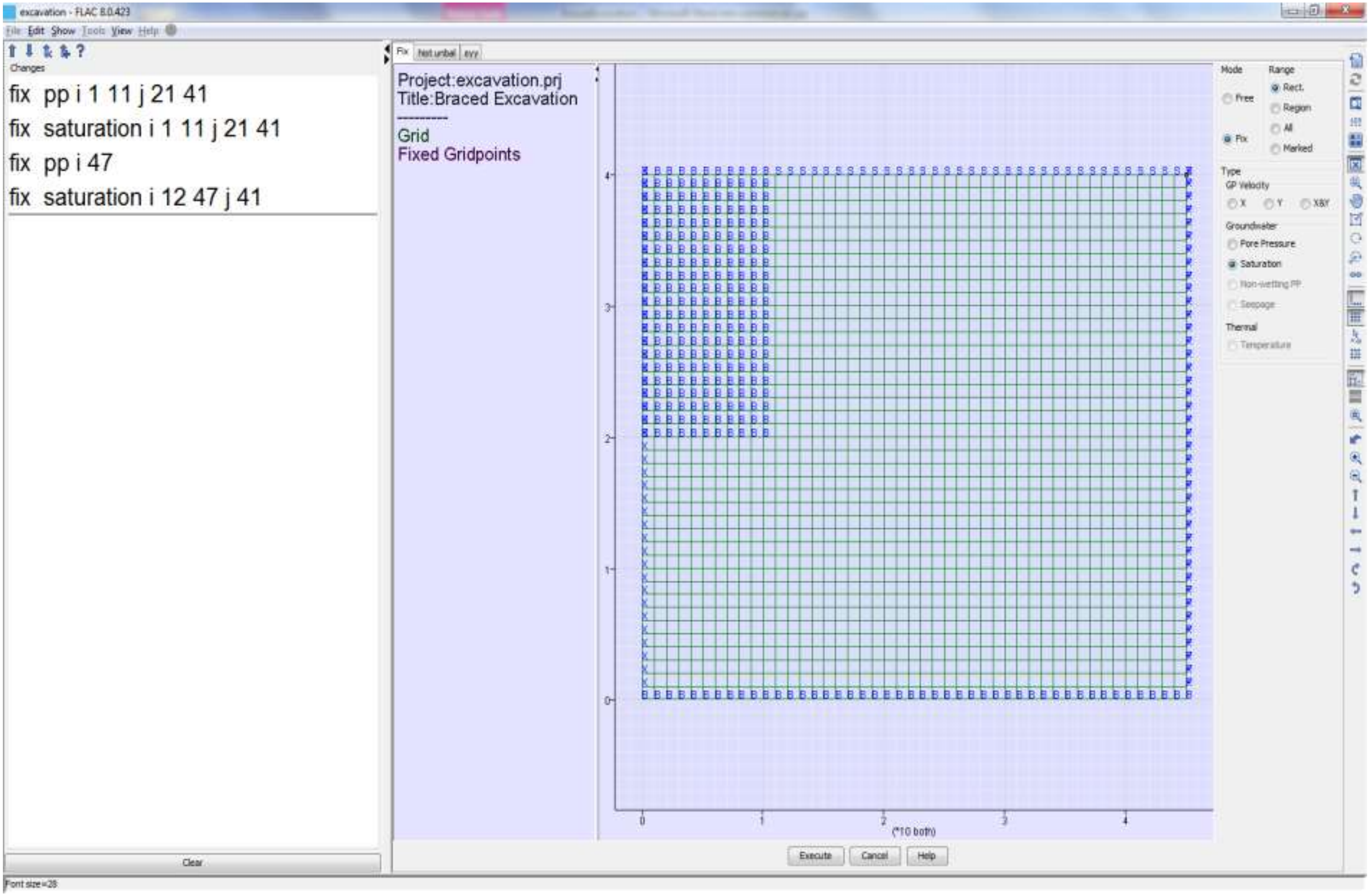
Step 3-2 Solve to reach a new equilibrium state with the diaphragm wall installed. Save the state as exc02mc.sav.



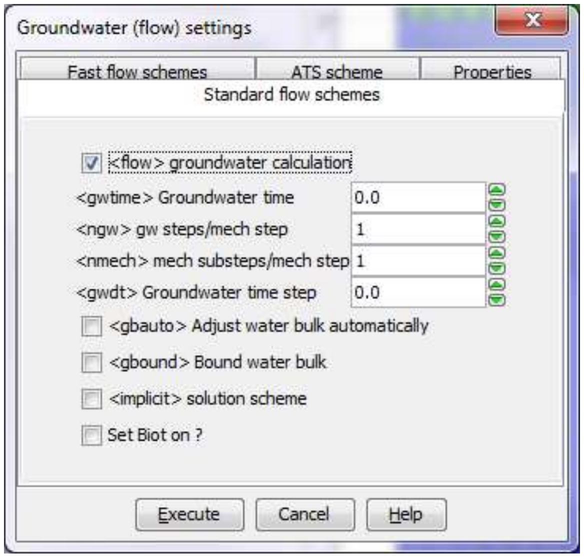
Step 4-1 Dewater to a depth of 20 m inside the excavation region by first setting the pore pressure and saturation to zero in this region using the [In Situ]/[Initial] tool. Note that displacements and velocities are also reset to zero with the [Clear? Displmt & velocity] button.

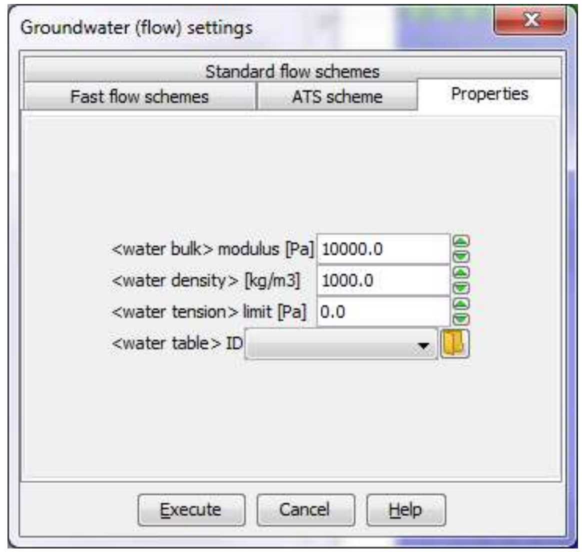


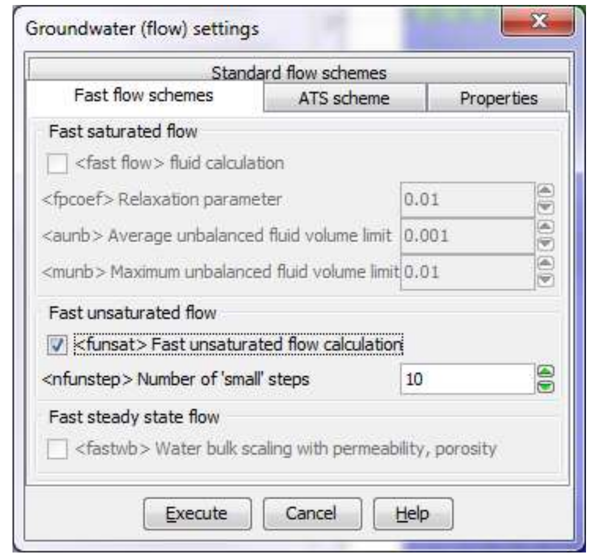
Step 4-2 Pore pressure and saturation are fixed at zero in the [In Situ]/[Fix] tool



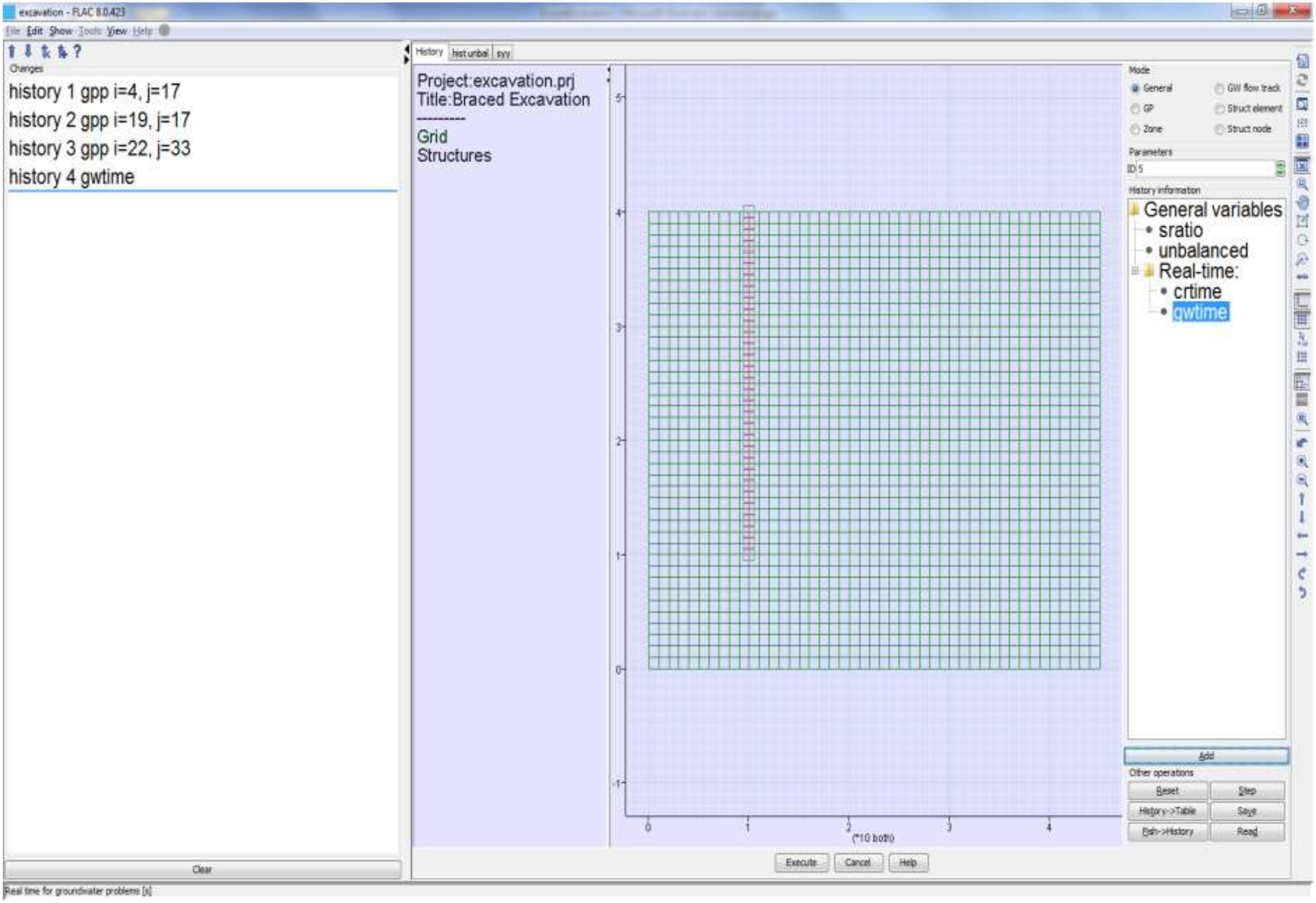
Step 4-3 Groundwater boundary conditions are also set in the [In Situ]/[Fix] tool by fixing the pore pressure distribution along the right boundary and fixing saturation along the top. (It is assumed the ground adjacent to the excavation remains fully saturated.)



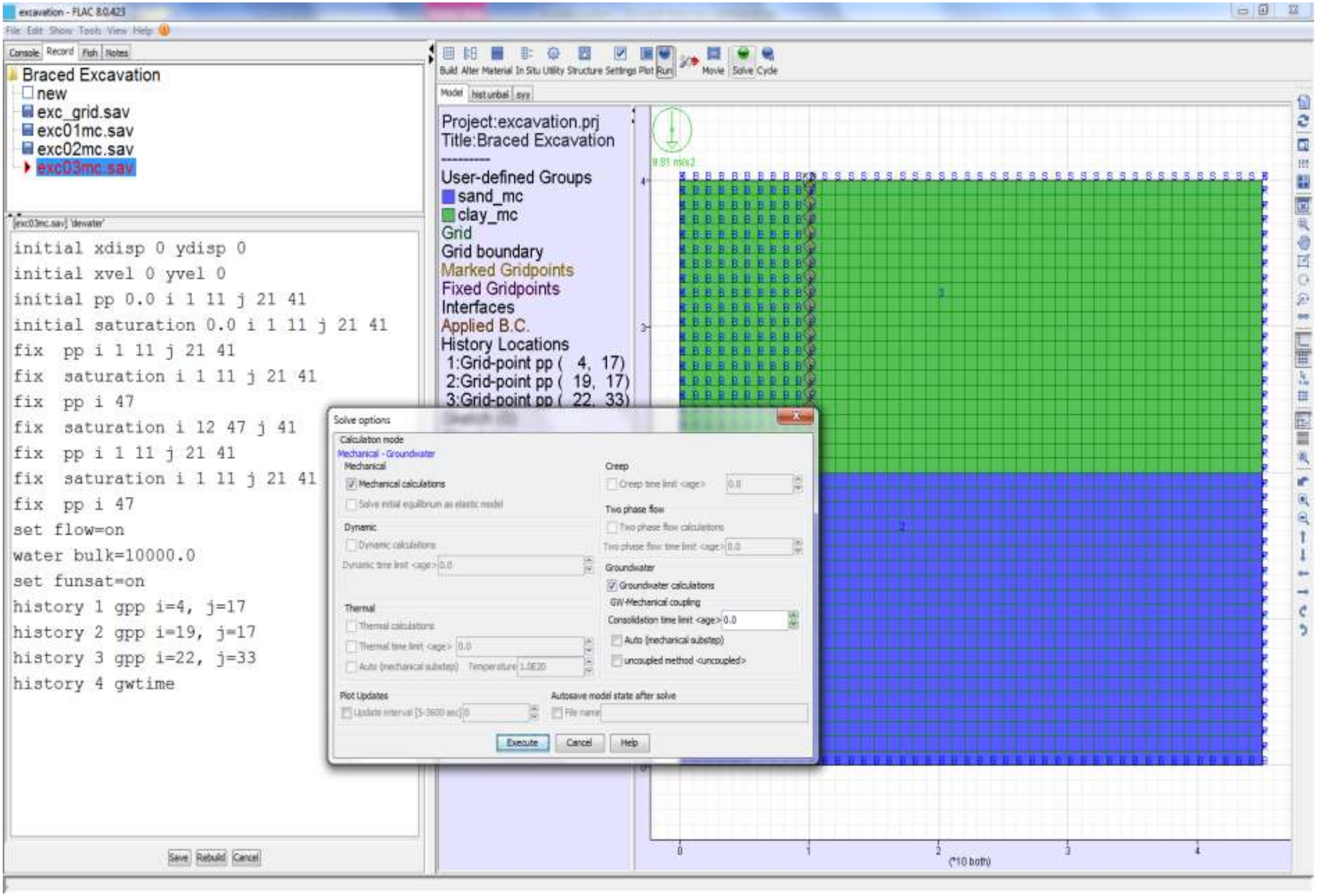




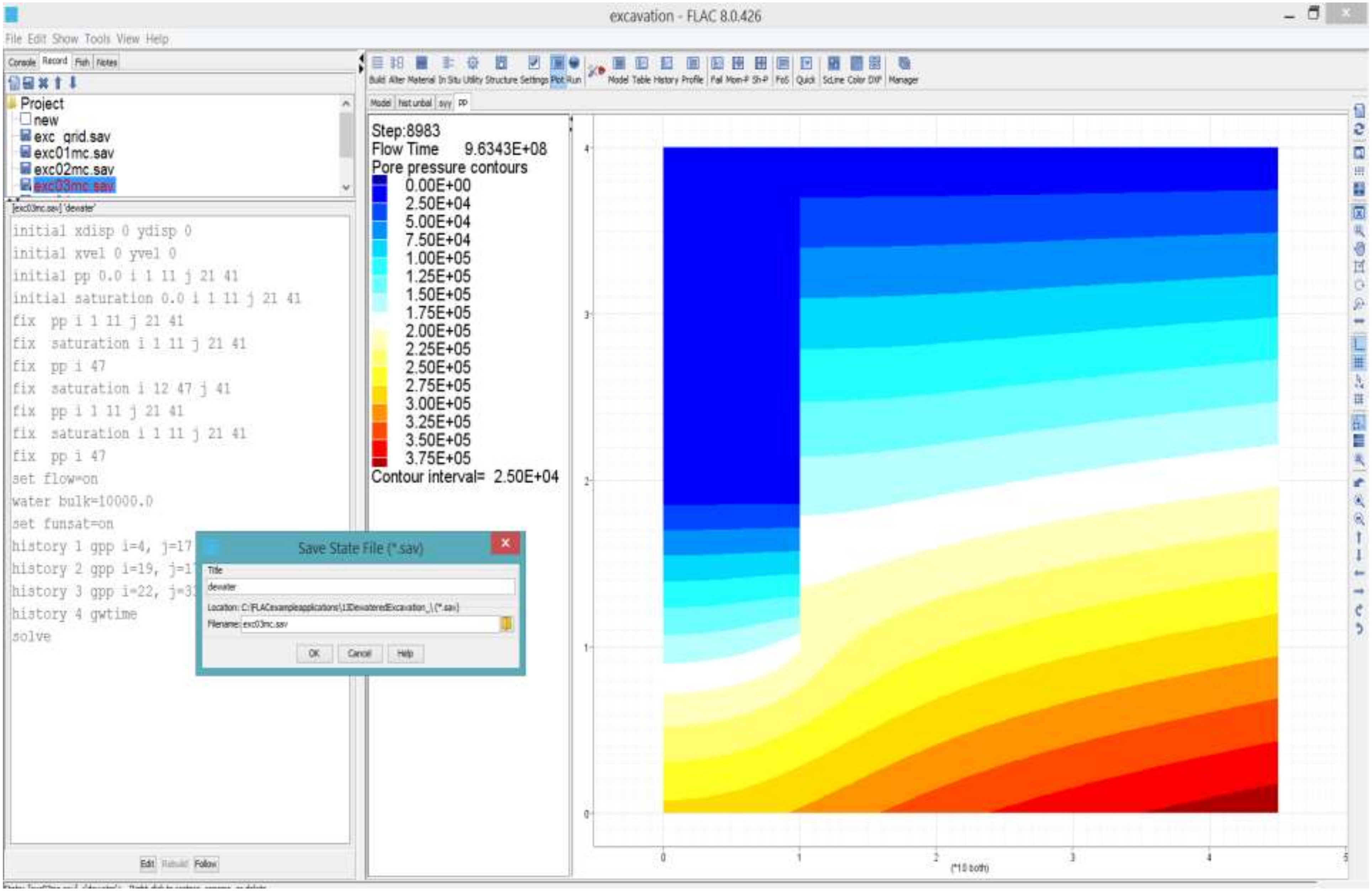
Step 4-4 Steady state flow conditions after dewatering are calculated as a coupled simulation. A coupled groundwater flow-mechanical calculation to steady state is run by turning the flow calculation on (in [Settings]/[GW]) . The fast unsaturated flow calculation is checked (funsat), and the fluid bulk modulus is set to 10000 Pa in order to speed the calculation to steady state.



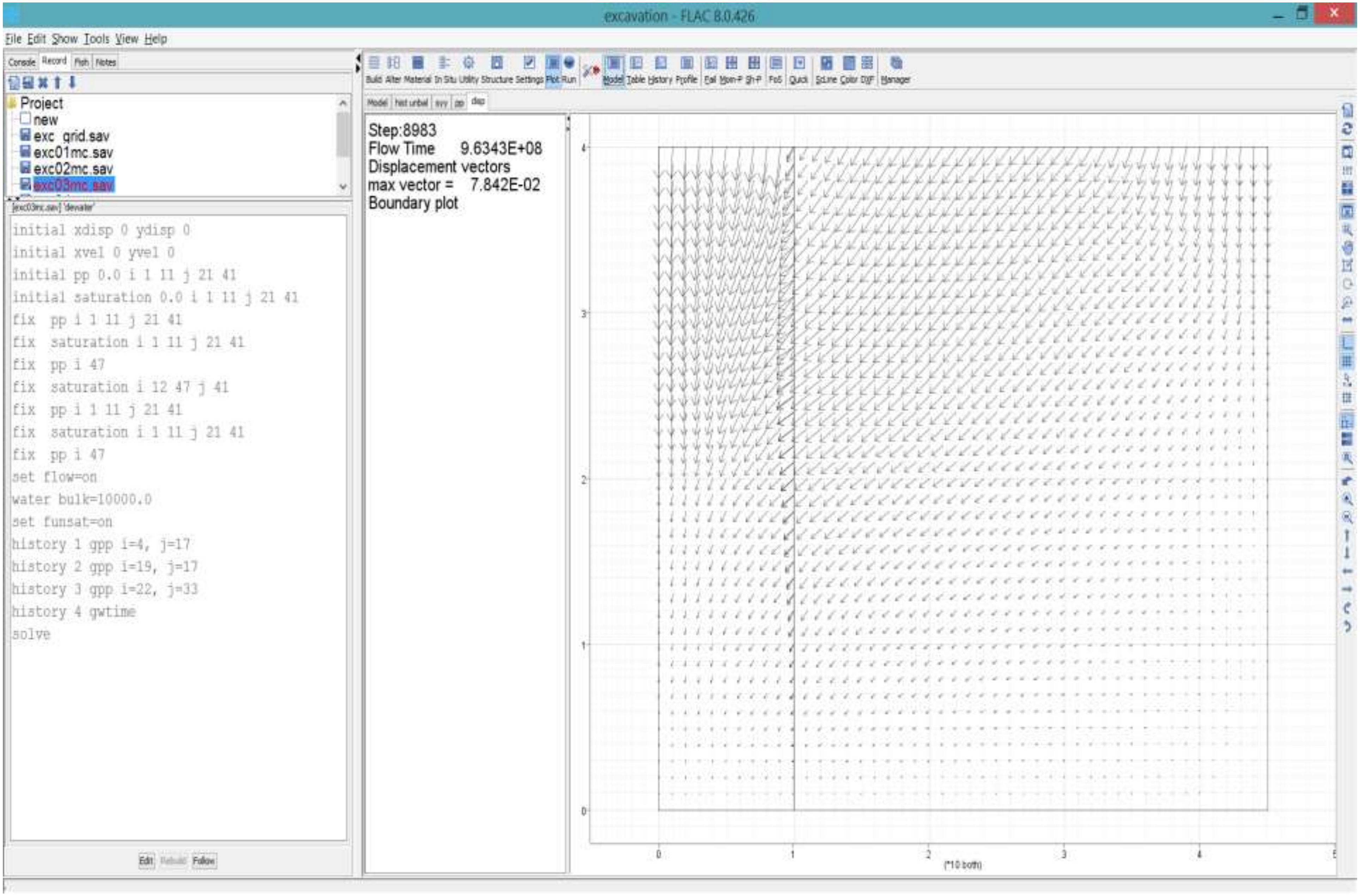
Step 4-5 Pore pressure histories are recorded in the [Utility]/[History] tool.



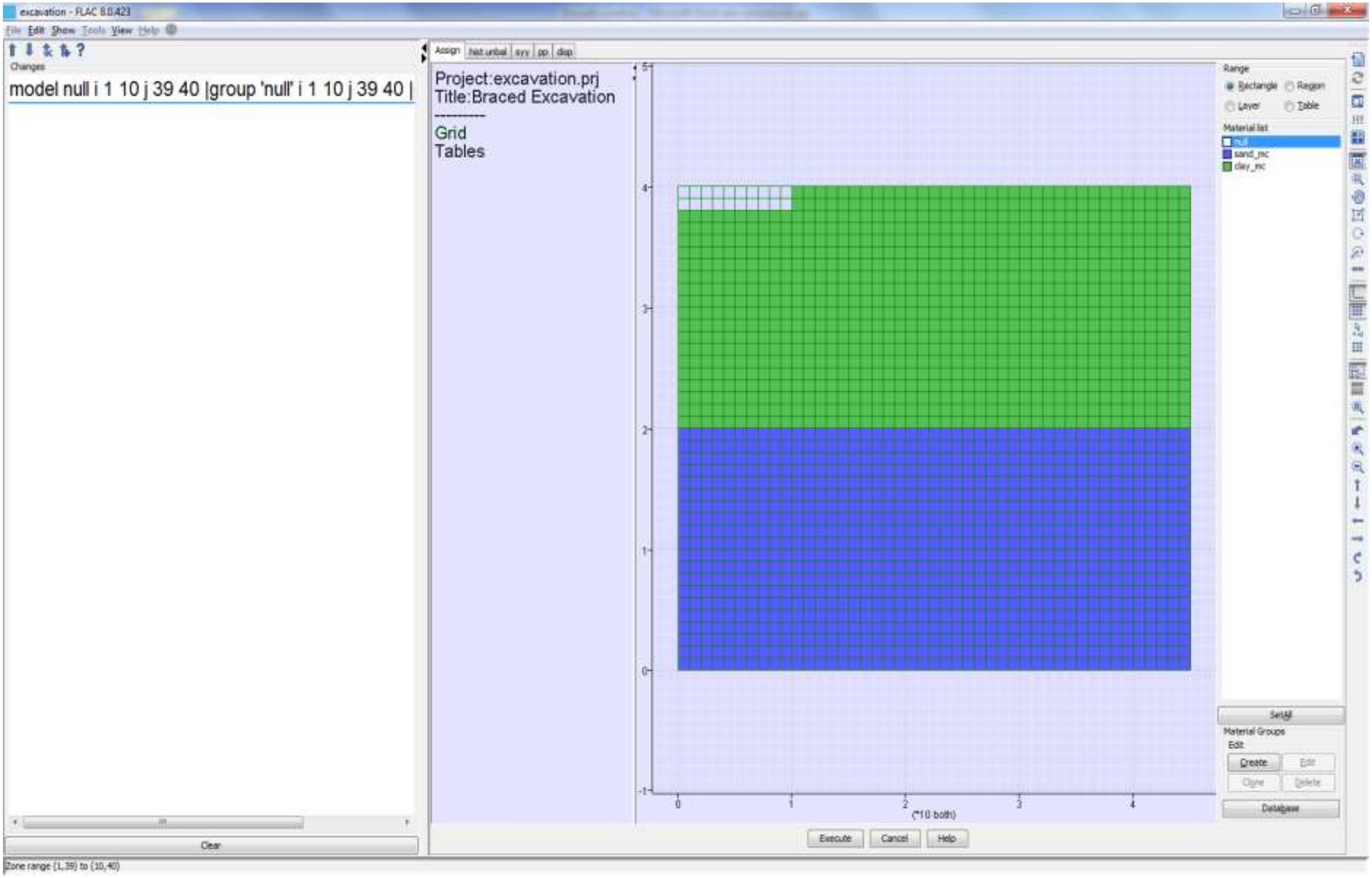
Step 4-6 The couple mechanical-groundwater calculation is run until steady flow state is reached using the [Run]/[Solve] tool.



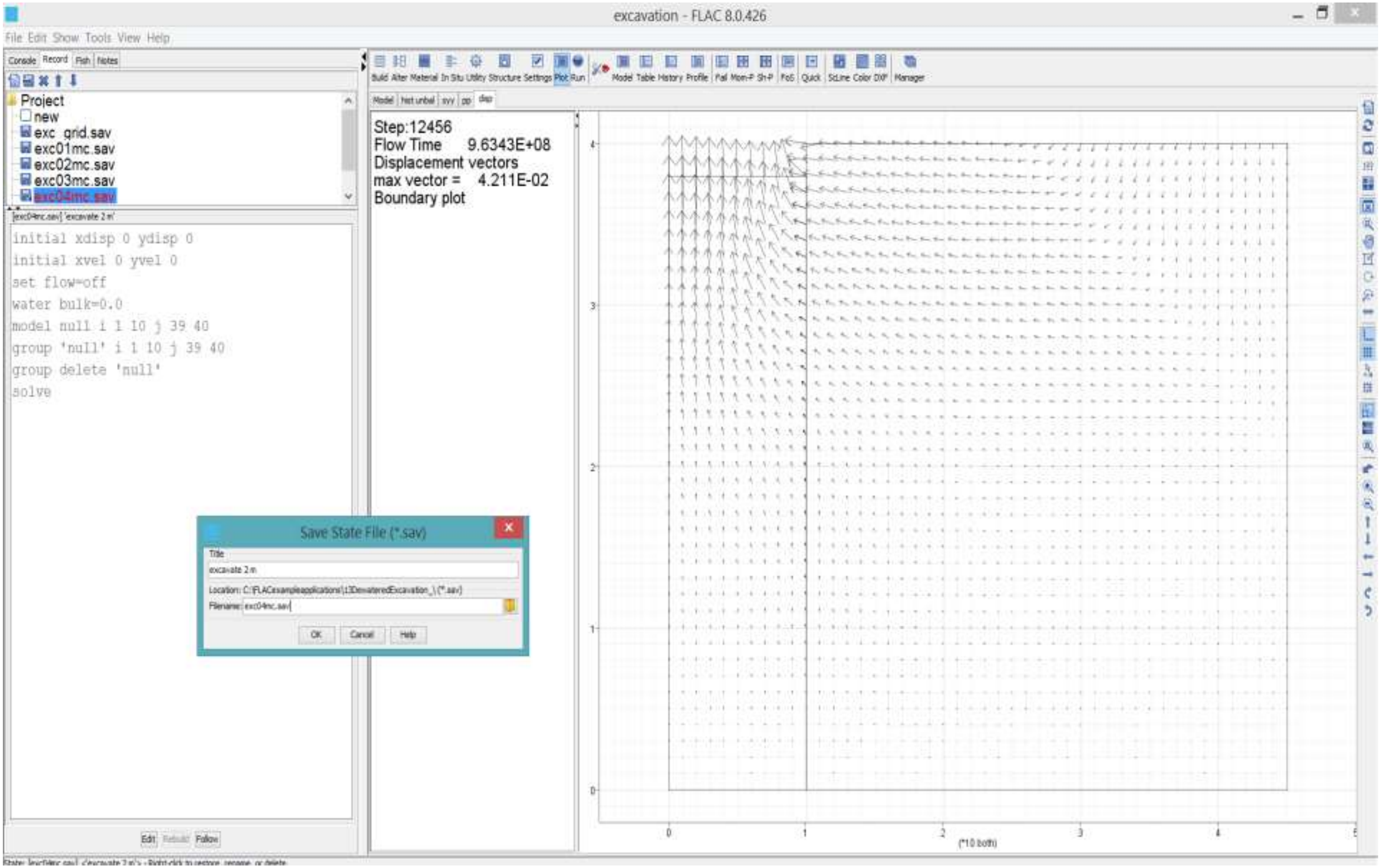
Step 4-7 The pore pressure distribution is plotted at steady state. The state is saved as exc03mc.sav.



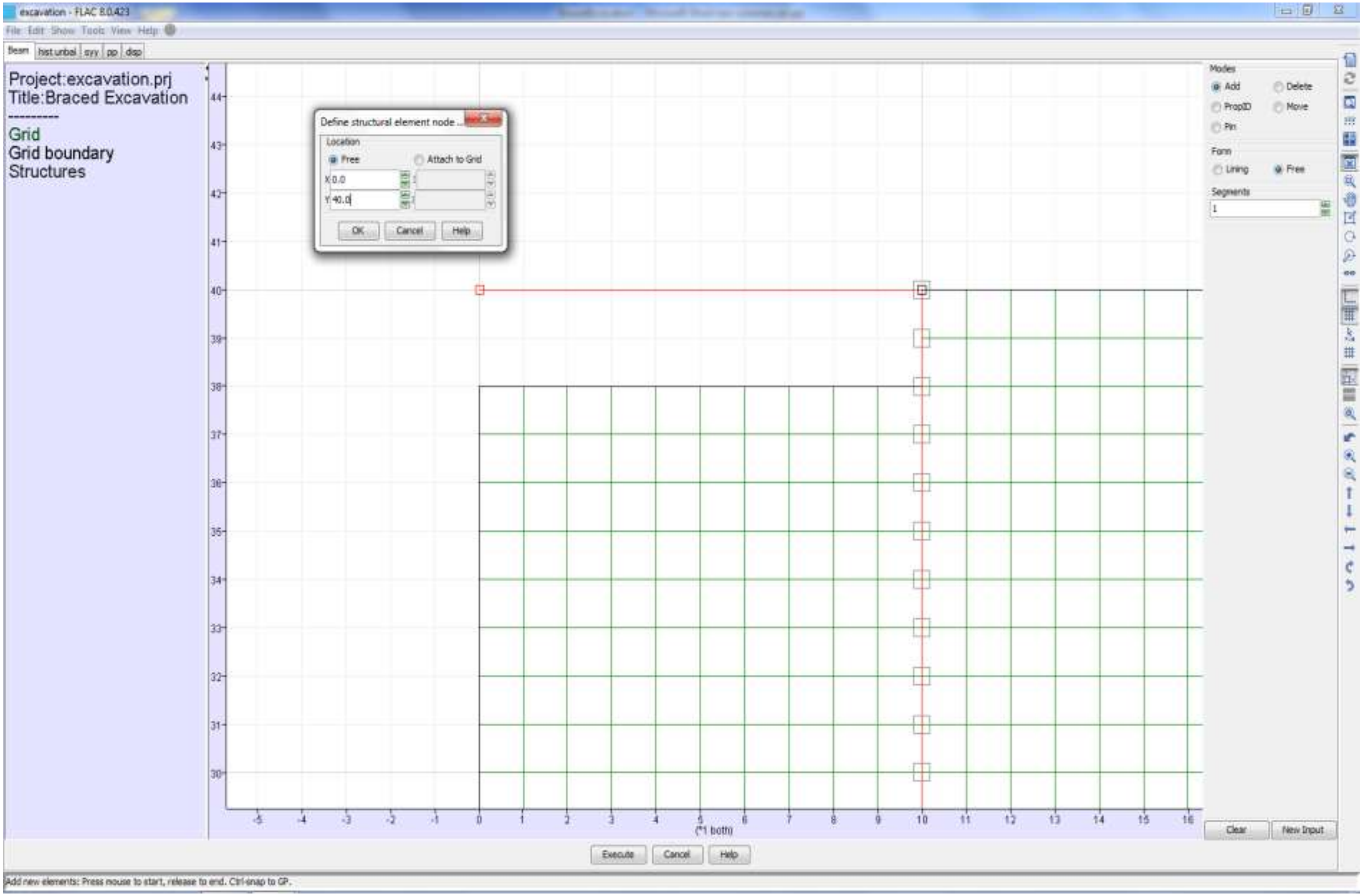
Step 4-8 Displacement vectors are plotted to show the amount of settlement due to dewatering.



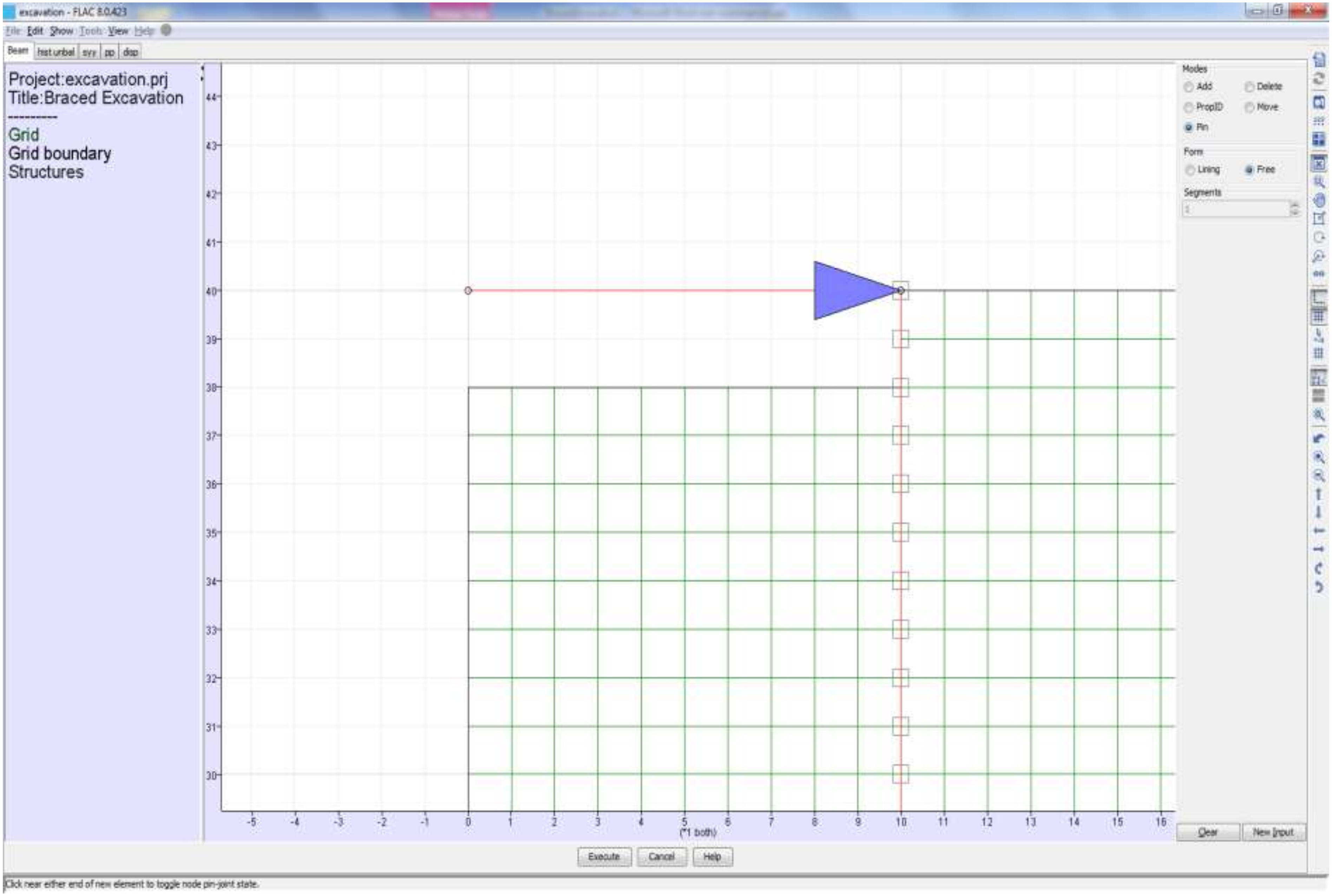
Step 5-1 Displacements are velocities are reset to zero in the [In Situ]/[Initial] tool, fluid flow is turned off and water bulk modulus is set to zero in the [Settings]/[GW] tool Excavation to 2 m is performed by nulling zones to a 2 m depth between the diaphragm walls using the [Material]/[Assign] tool.



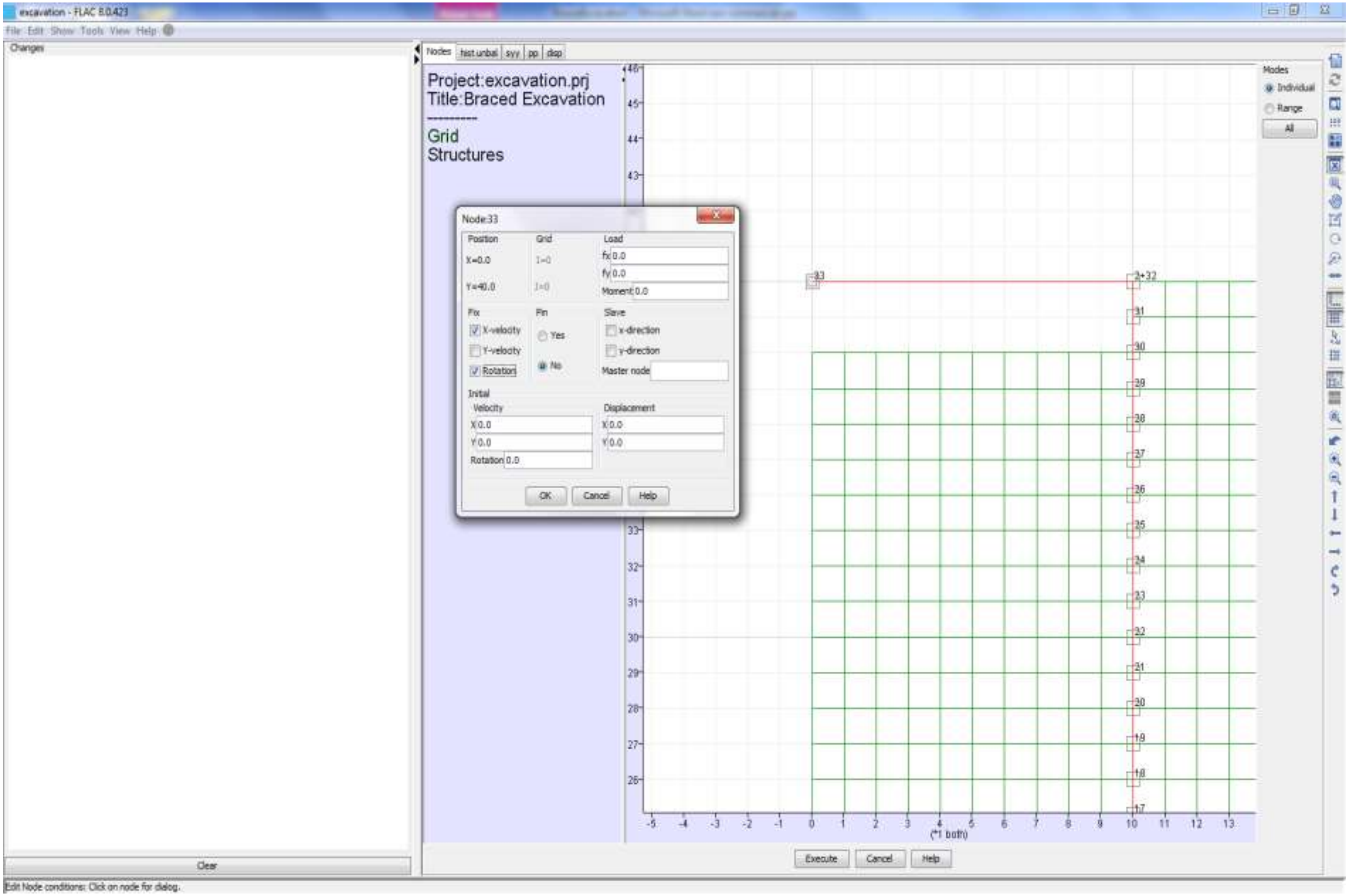
Step 5-2 The model is run to equilibrium with the [Run]/[Solve] tool. Displacement vectors indicate the heave that occurs. The state is saved as exc04mc.sav.



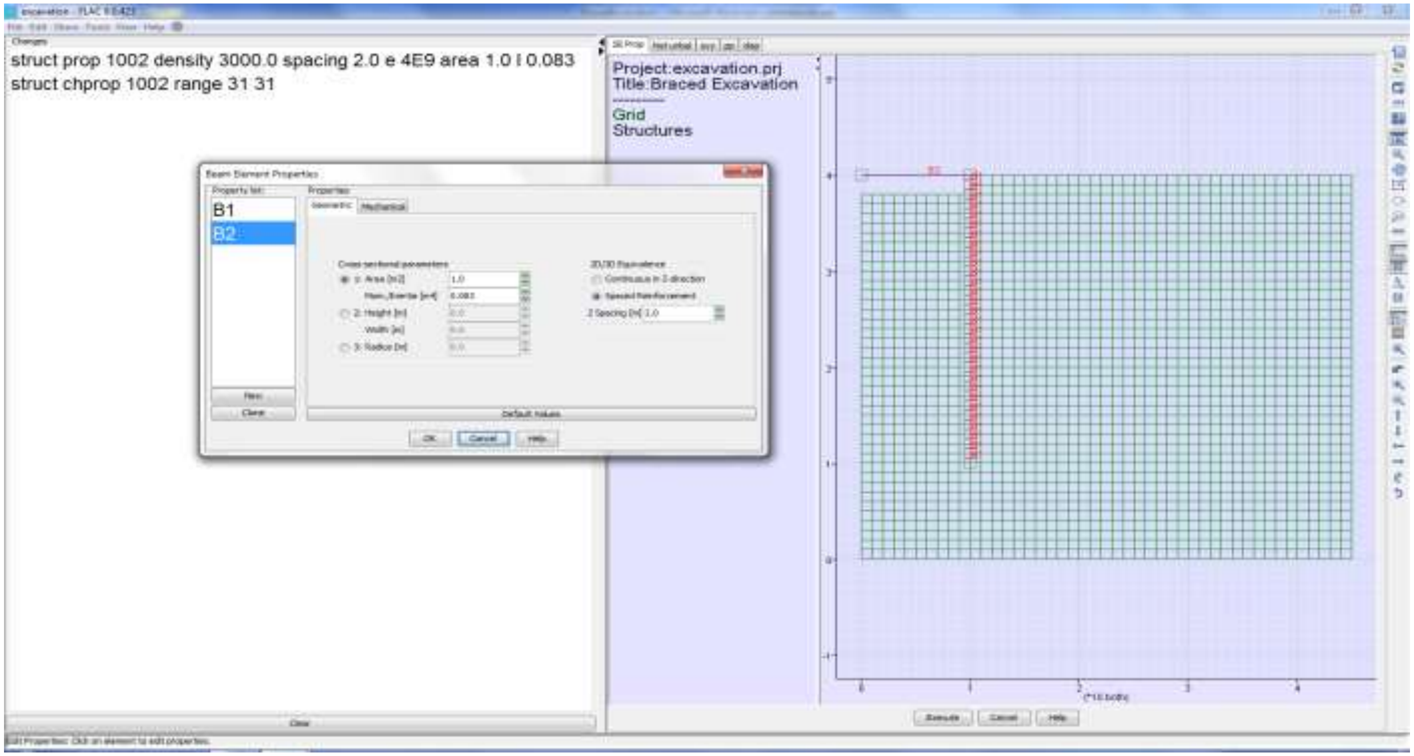
Step 6-1 A horizontal strut is installed at the top of the walls using the [Structure]/[Beam] tool. Click on the left node to locate the position at x=0, y=40.

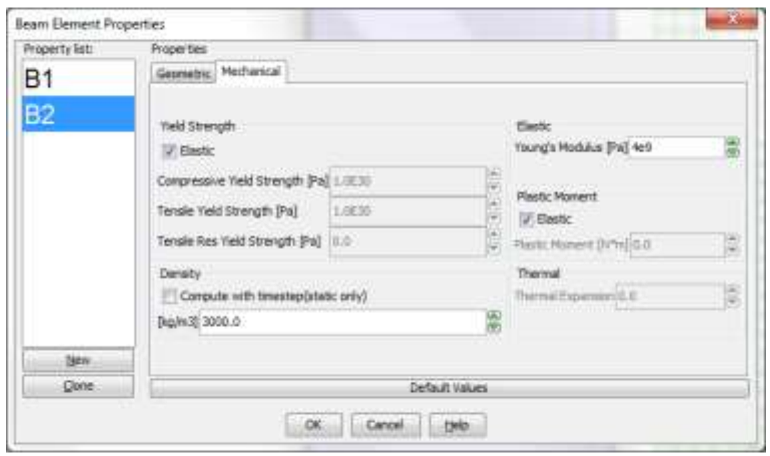


Step 6-2 Pin connection between the strut and wall is assigned using the [Pin] mode.

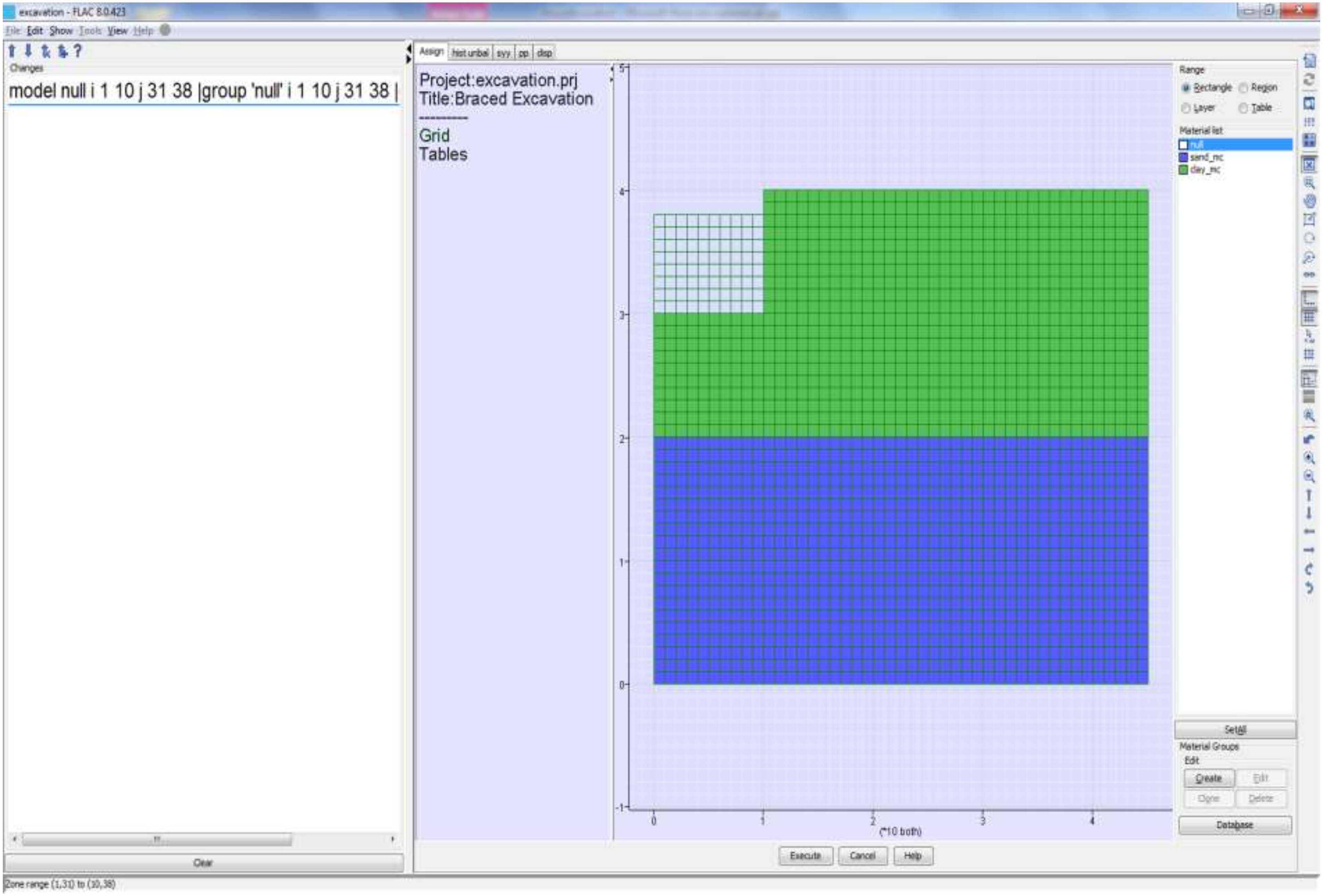


Step 6-3 The left node at x=0 is fixed in the x-direction and rotation (appropriate for a node located at the line of symmetry).

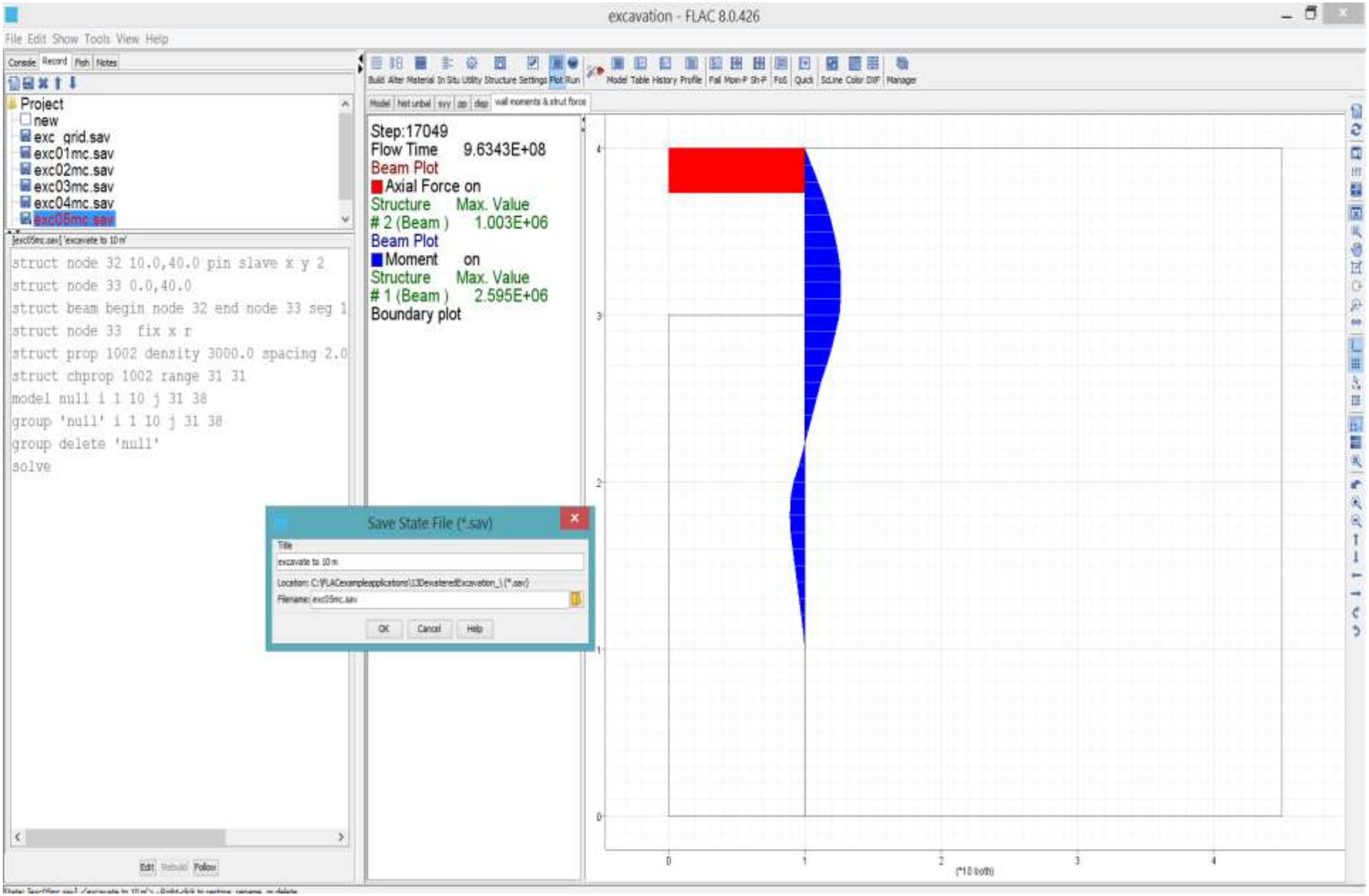




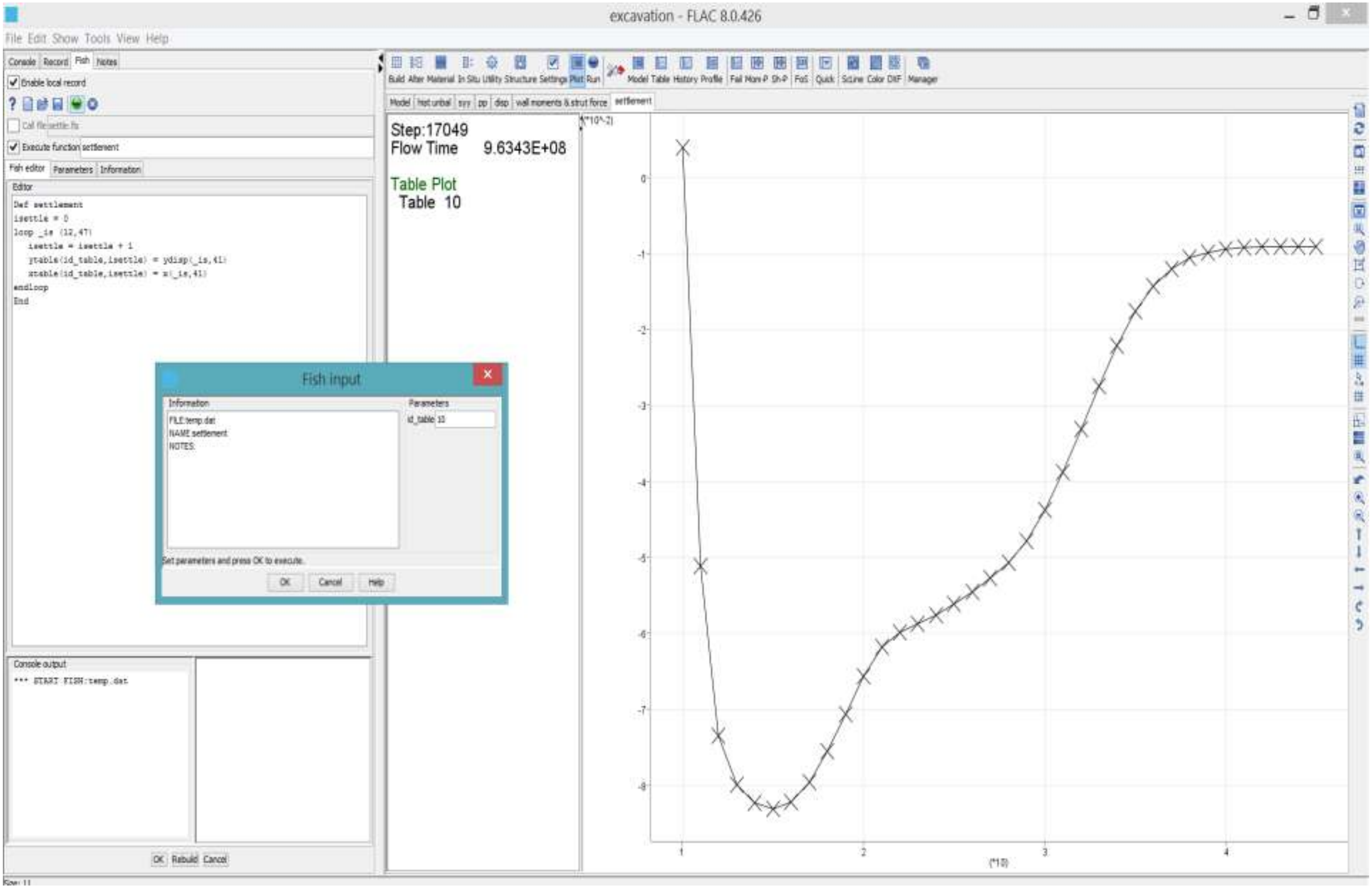
Step 6-4 Assign properties to the strut using the [Structure]/[SEProp] tool



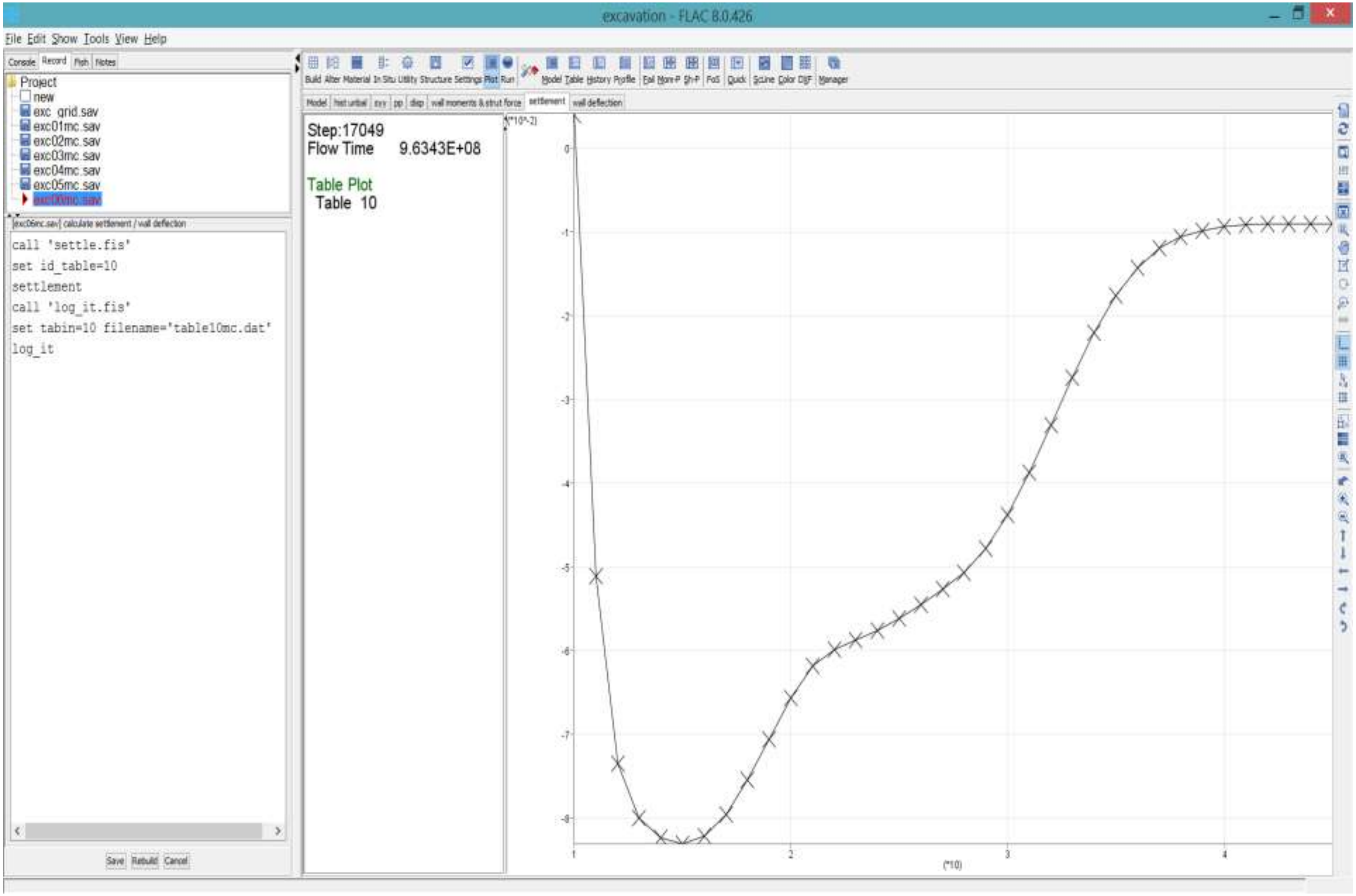
Step 6-5 Excavate to 10 m depth by nulling zones in the [Material]/[Assign] tool.



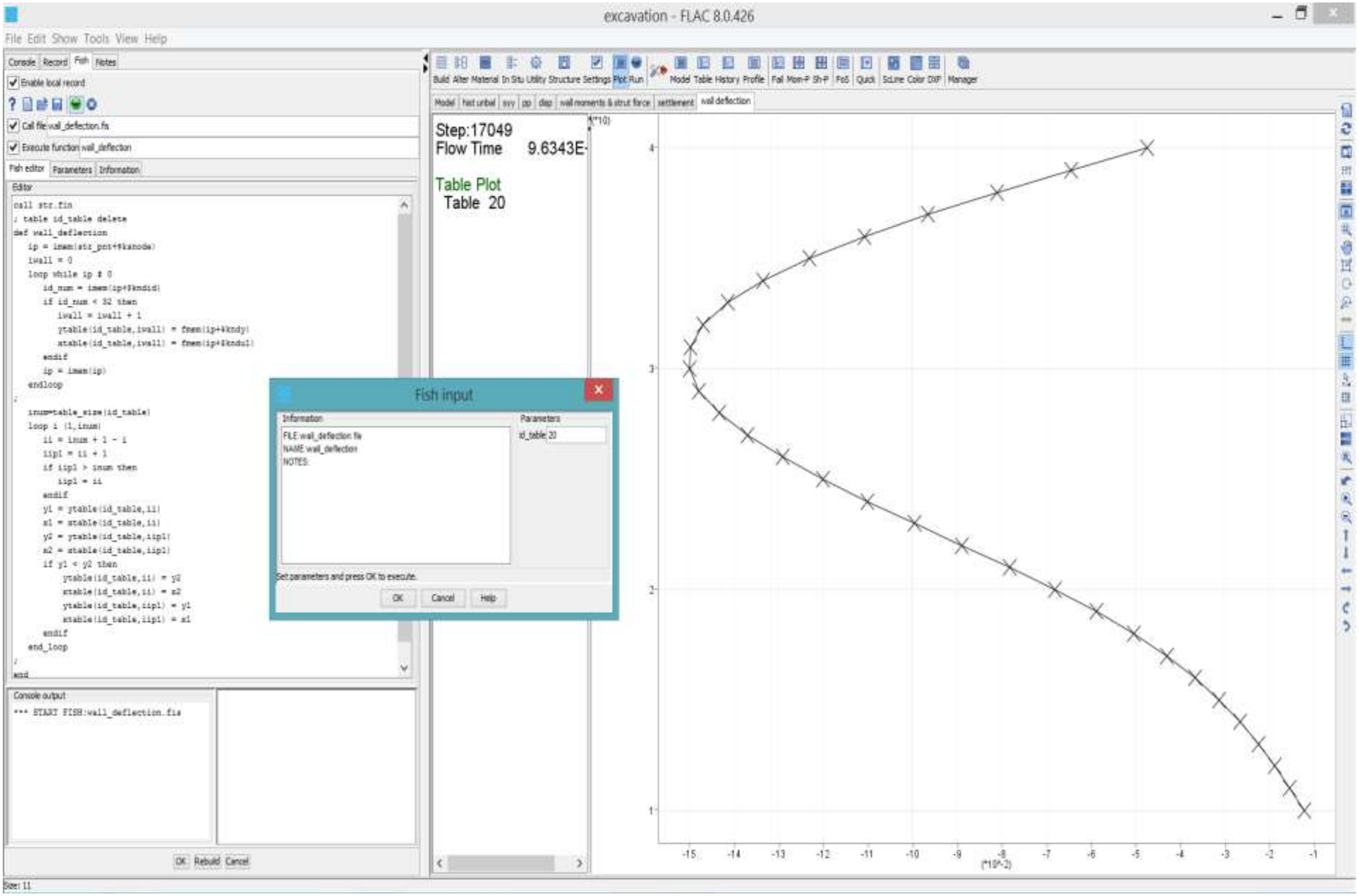
Step 6-6 Moment distribution in the wall and axial force in the strut are plotted. The state is saved as exc05mc.sav.



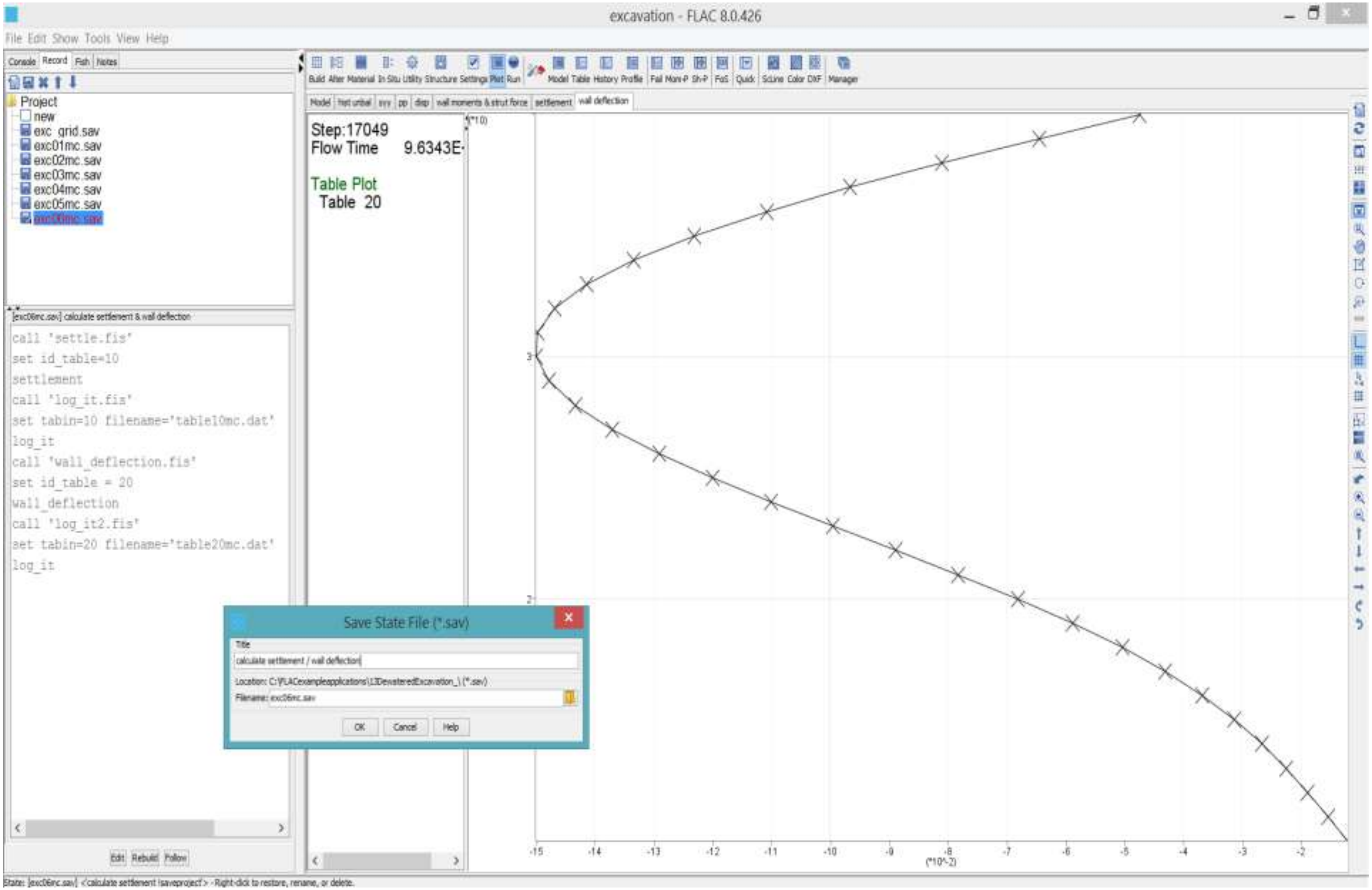
Step 6-7 Calculate surface settlement using FISH function SETTLE.FIS.



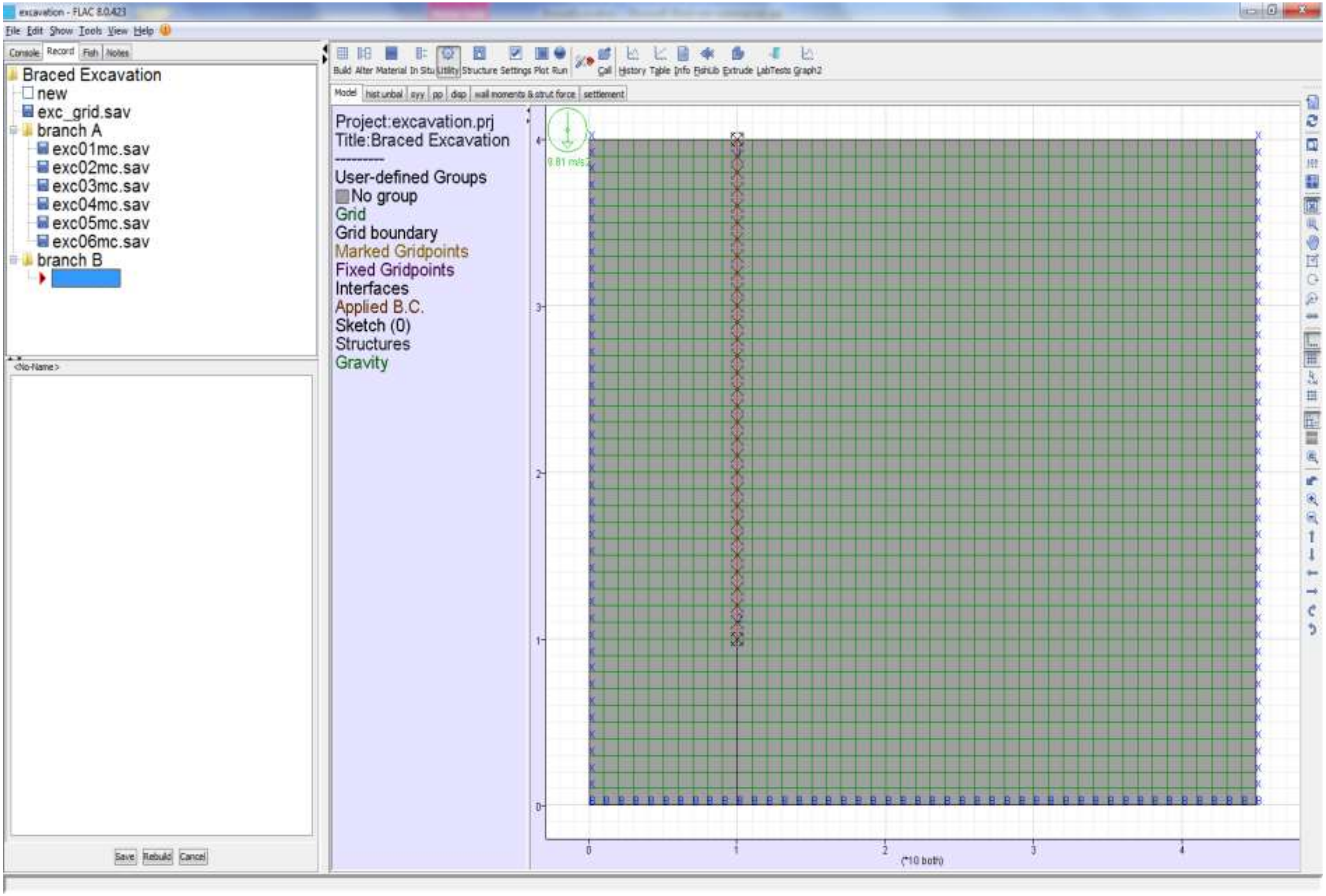
Step 6-8 The settlement table is written to file table10mc.dat using FISH function log_it.fis.



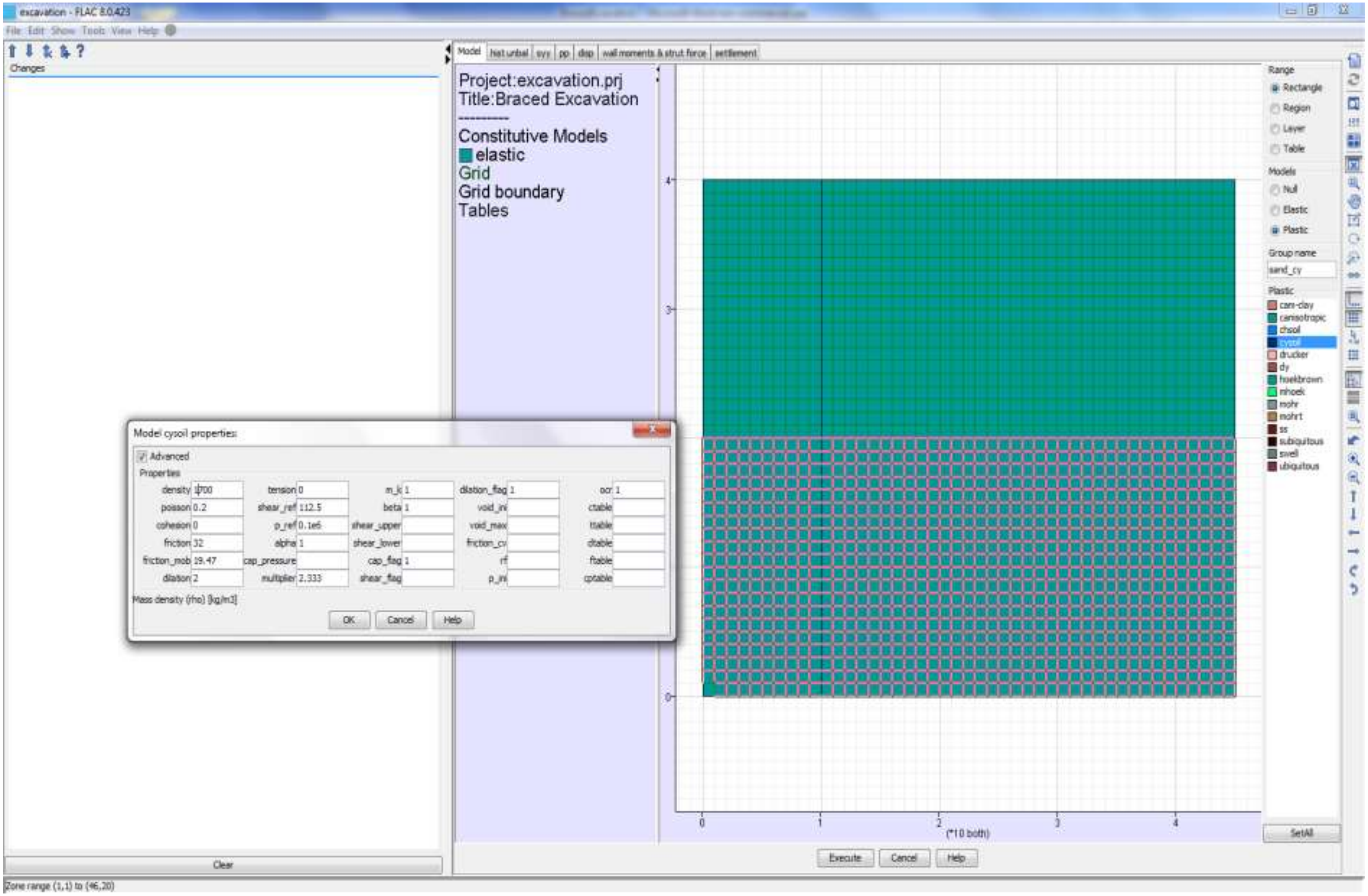
Step 6-9 Calculate wall deflection using FISH function WALL_DEFLECTION.FIS.



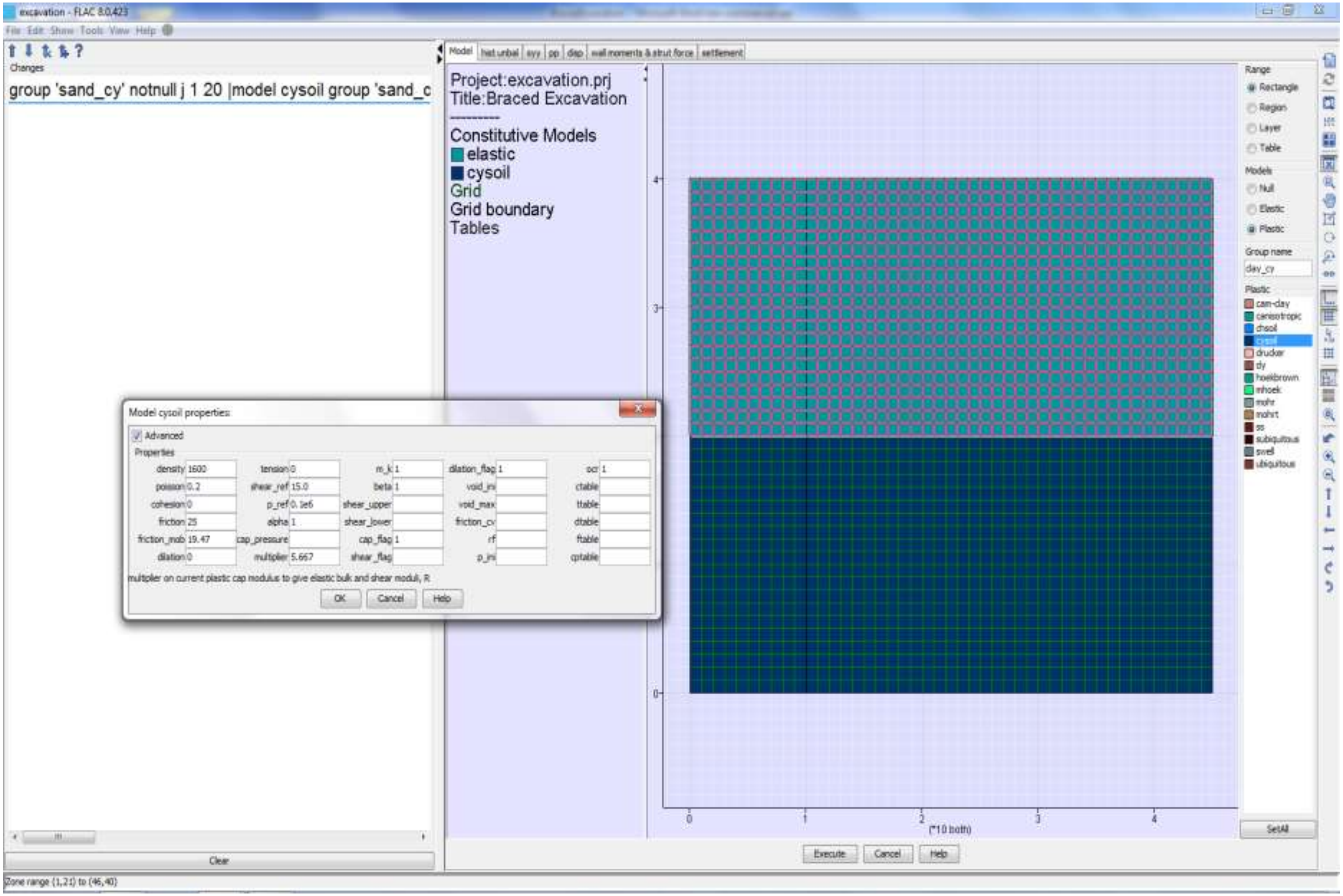
Step 6-10 The wall deflection table is written to file table20mc.dat using FISH function log_it2.fis. Save the state as exc06mc.sav.



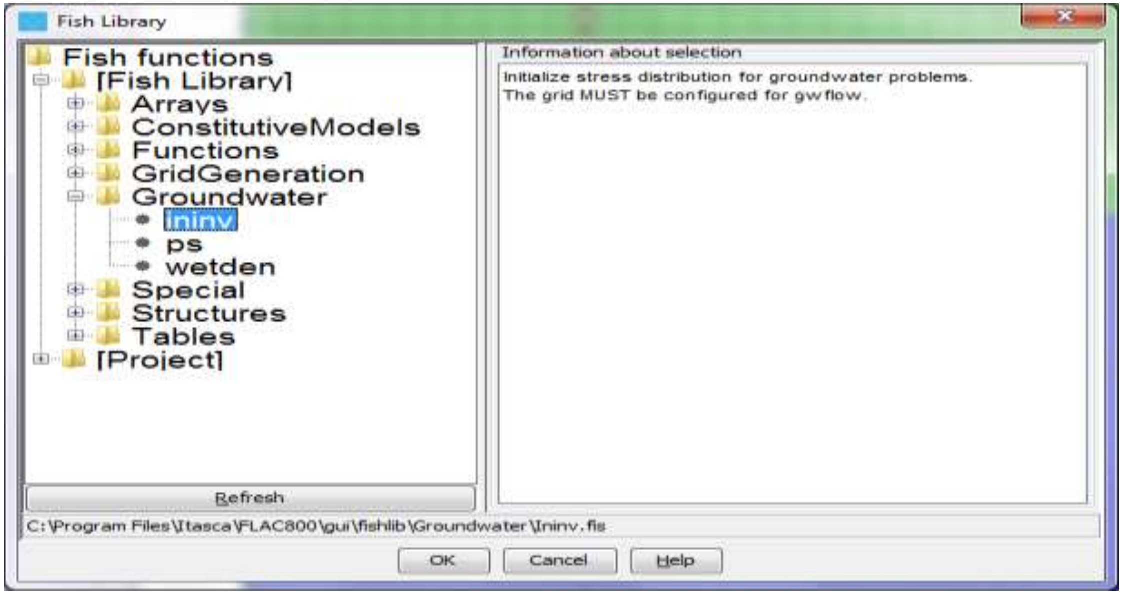
Step 2cy-1 Create a separate branch starting from exc_grid.sav to repeat the simulation using the cysoil model.



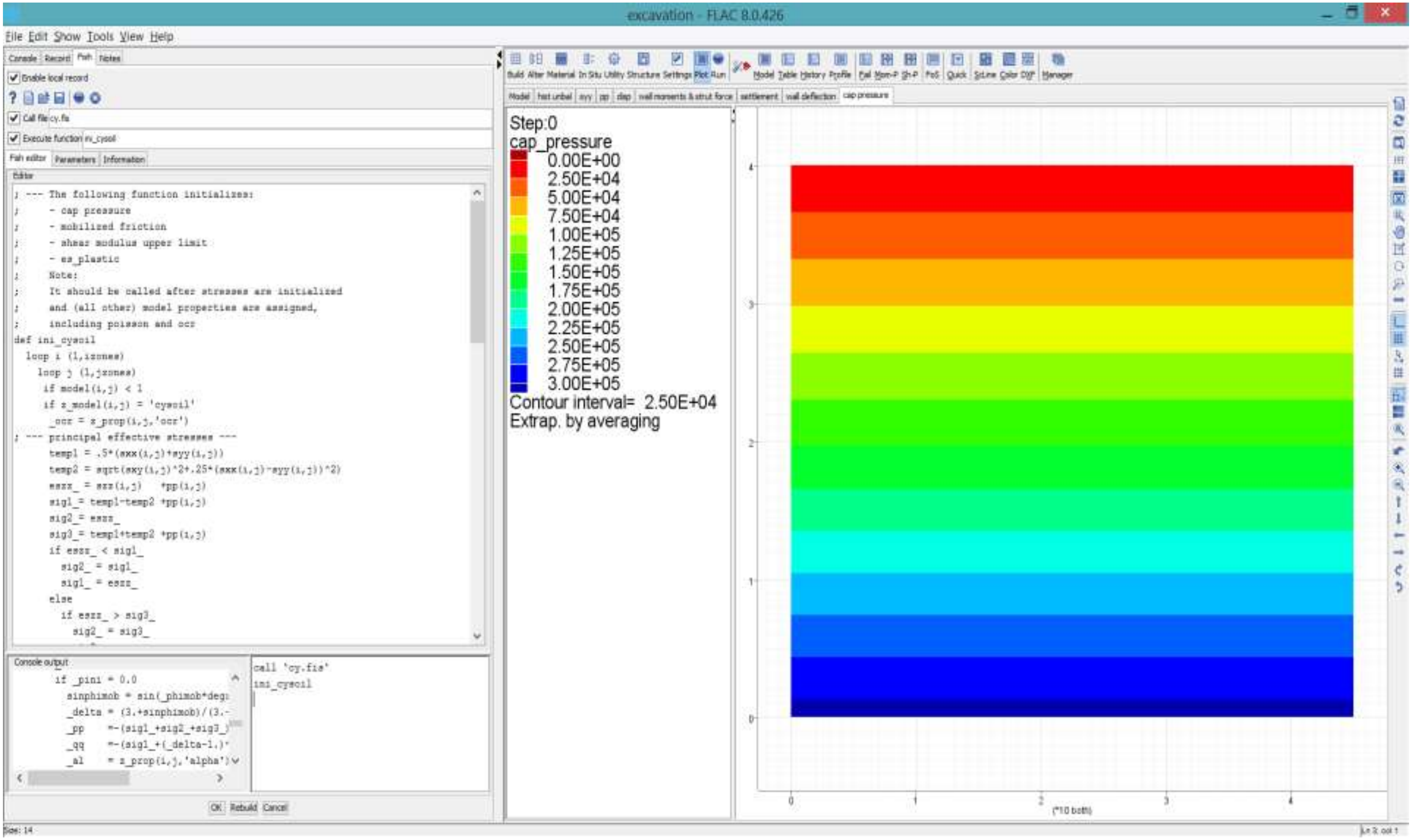
Step 2cy-2 Enter the [Assign]/[Model] tool, select the cysoil model, assign the group name sand_cy, and drag the mouse over zones from y=0 to y=20. Enter the cysoil properties for sand.



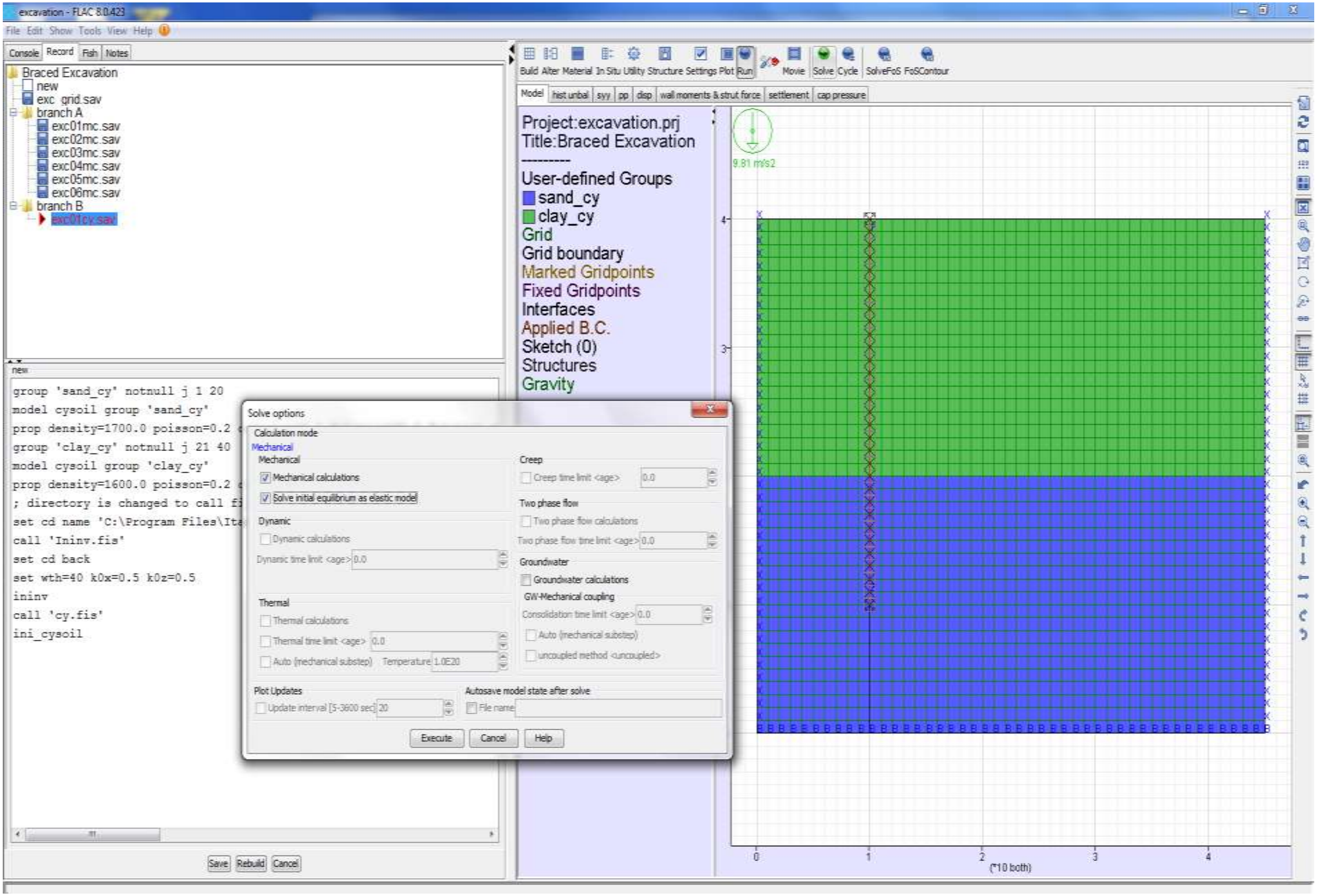
Step 2cy-3 Assign the group name clay_cy, and drag the mouse over zones from y=20 to y=40. Enter the cysoil properties for clay.



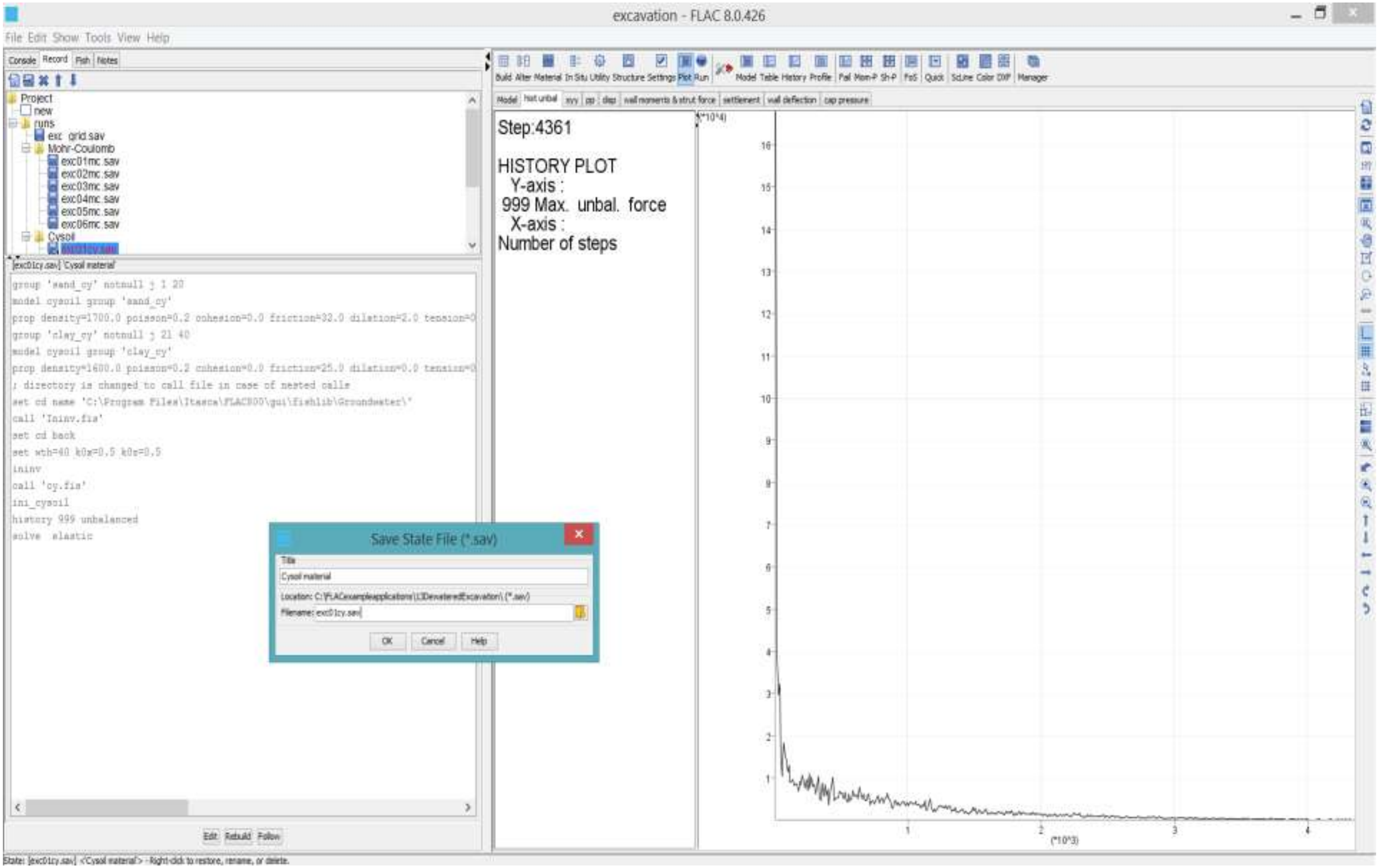
Step 2cy-4 Click on [Fish Library]/[Groundwater]/[ininv] to call in the ininv.fis function. Select [OK] and the Fish input dialog opens to enter the water table location and effective horizontal to vertical stress ratios.



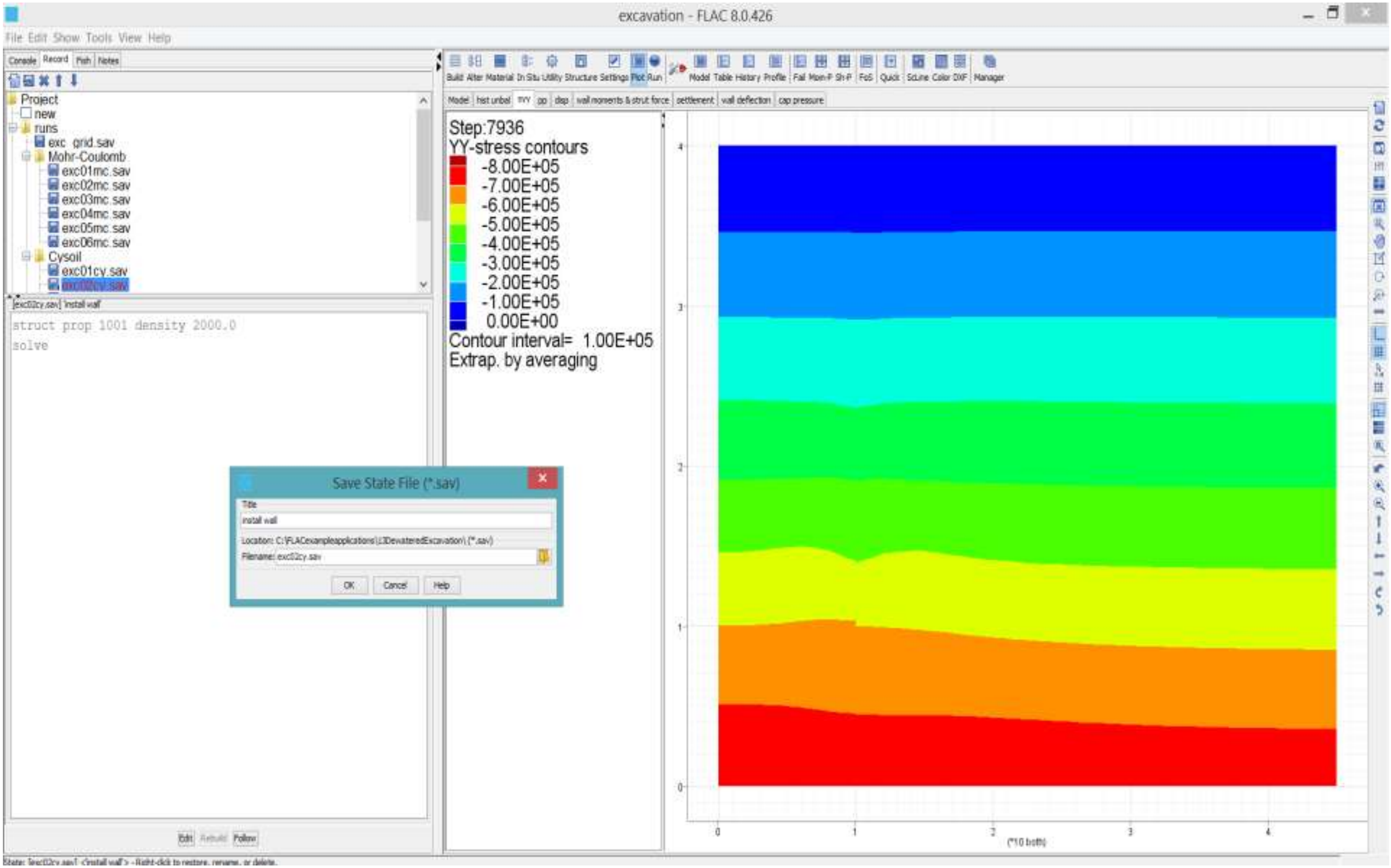
Step 2cy-5 FISH function cy.fis initializes mobilized friction, cap pressure, shear modulus upper limit and accumulated plastic shear strain which are stress dependent.



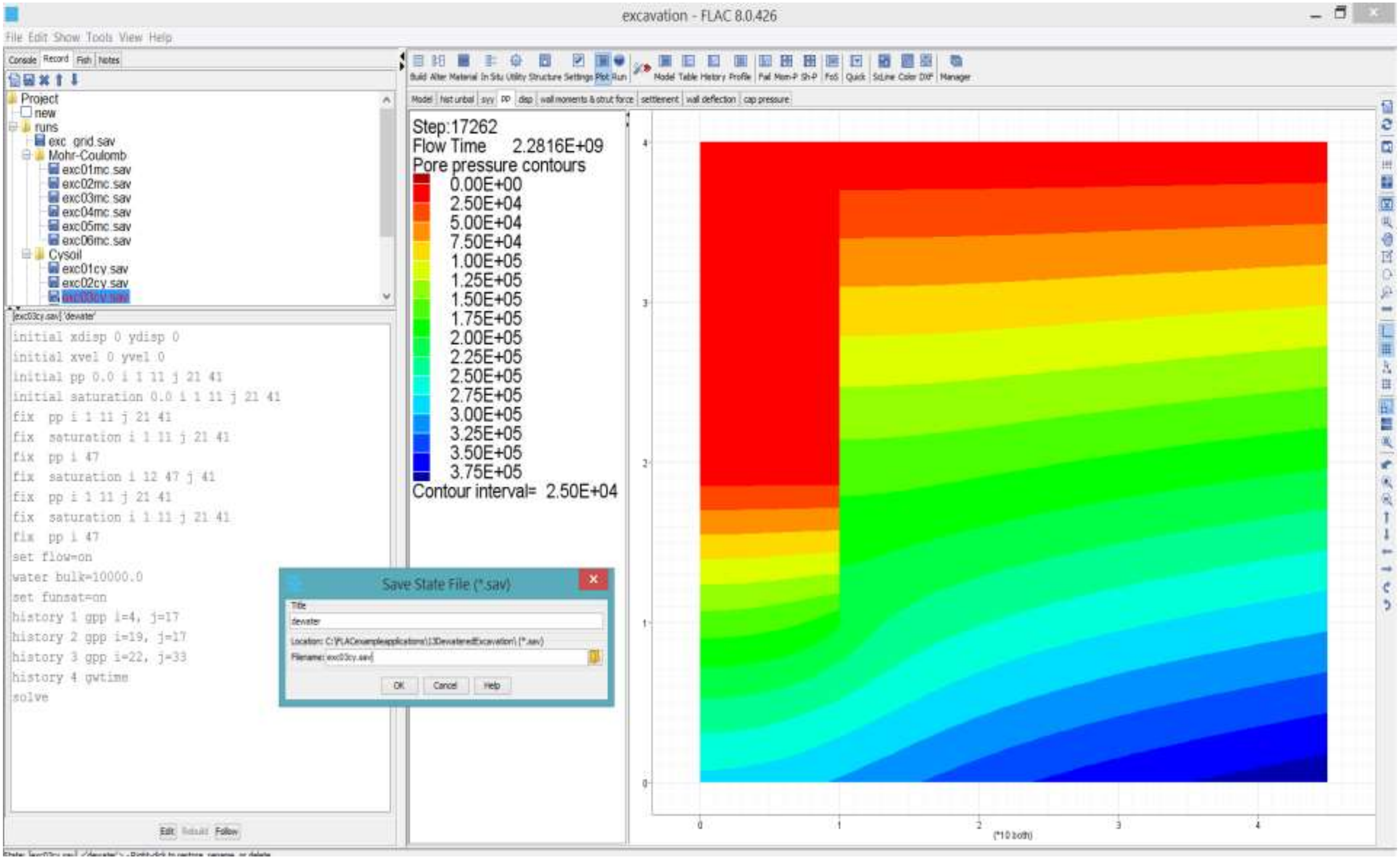
Step 2cy-6 Calculate the equilibrium state using [Run]/[Solve] and [Solve initial equilibrium as elastic model].



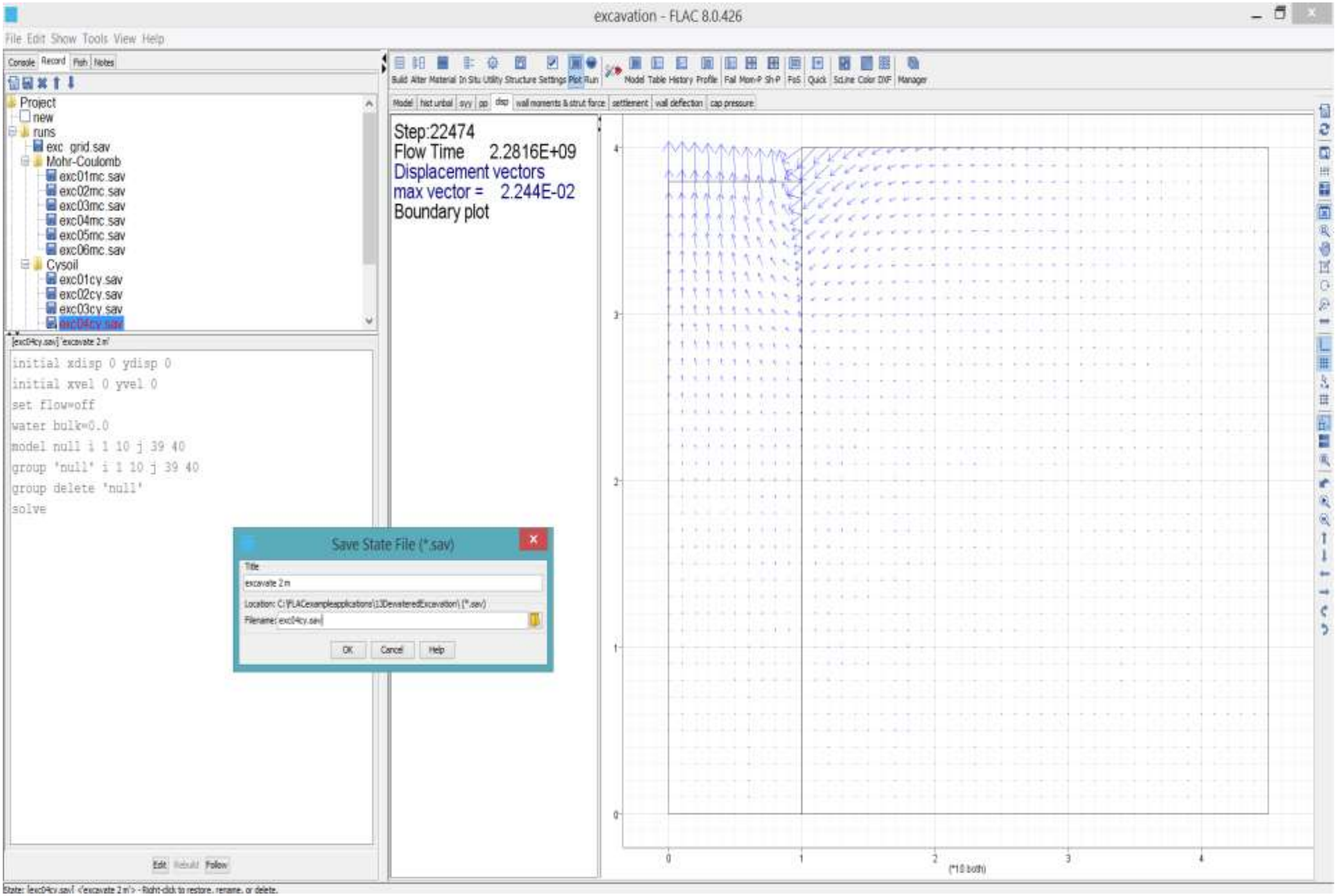
Step 2cy-7 Save the state as exc01cy.sav.



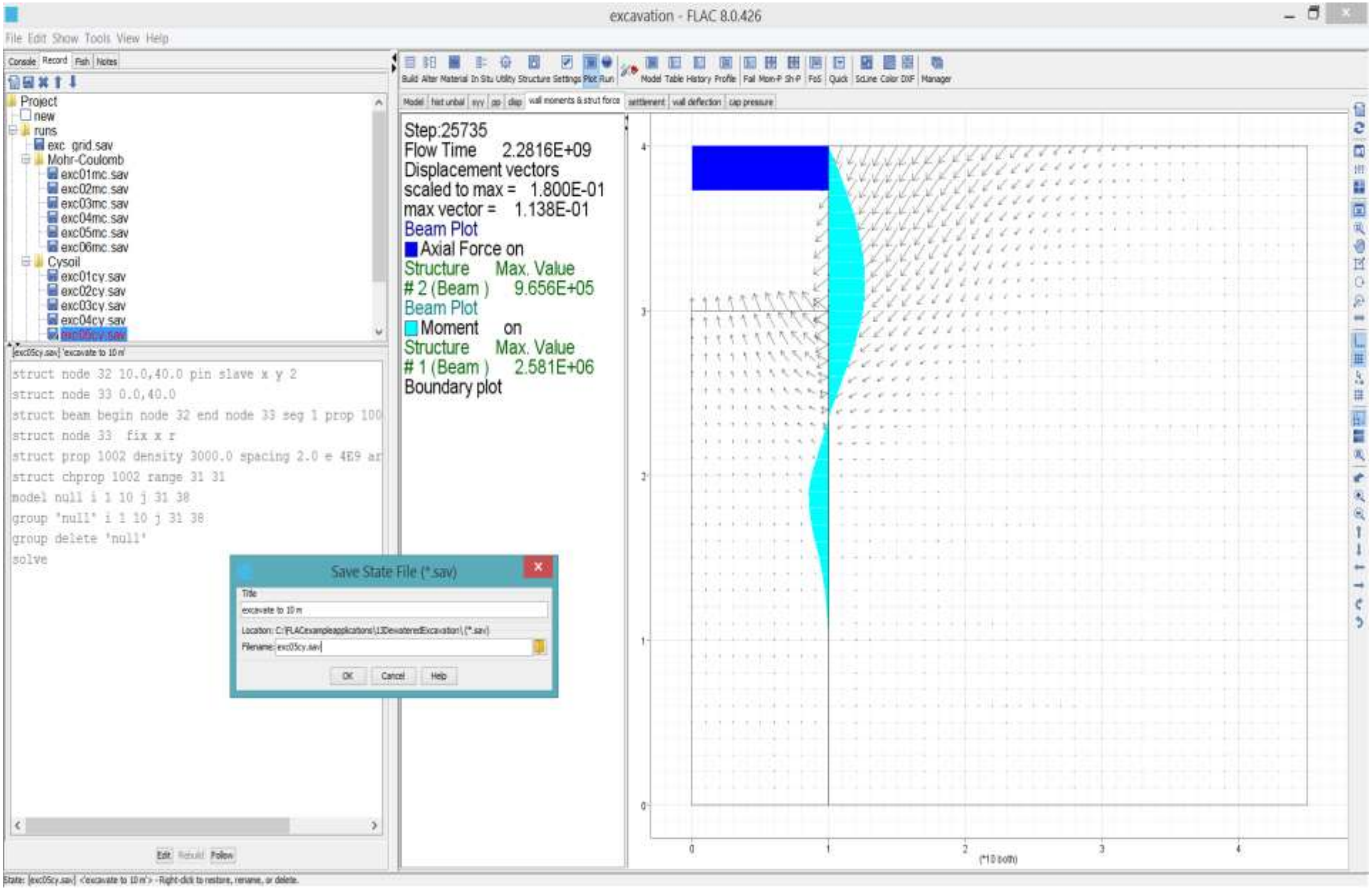
Step 3cy Add the wall and solve to equilibrium in the same steps as Step 3-1 and 3-2. Save the state as exc02cy.sav.



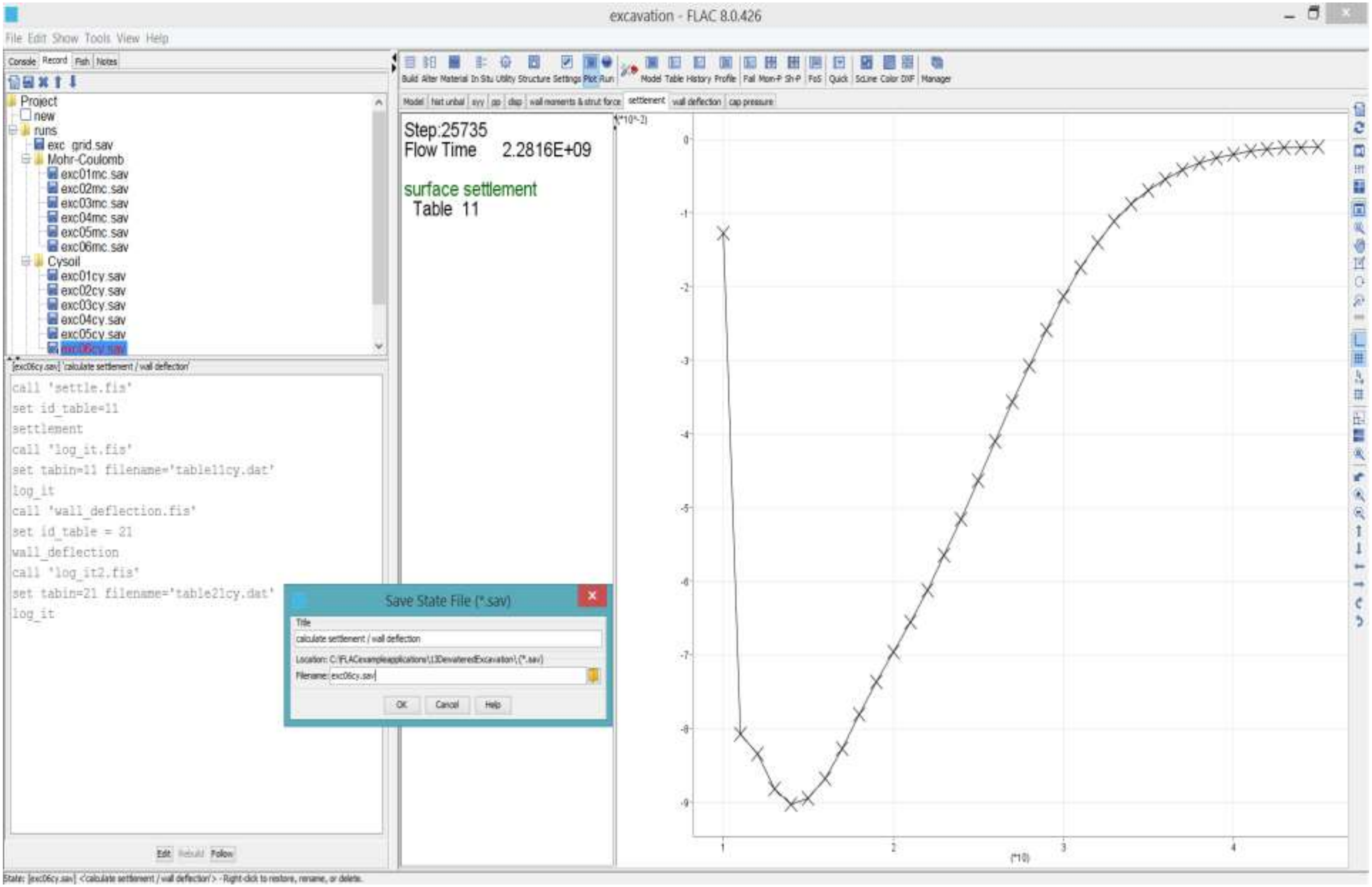
Step 4cy Repeat Steps 4-1 to 4-7 to dewater the excavation. Save the state as exc03cy.sav.



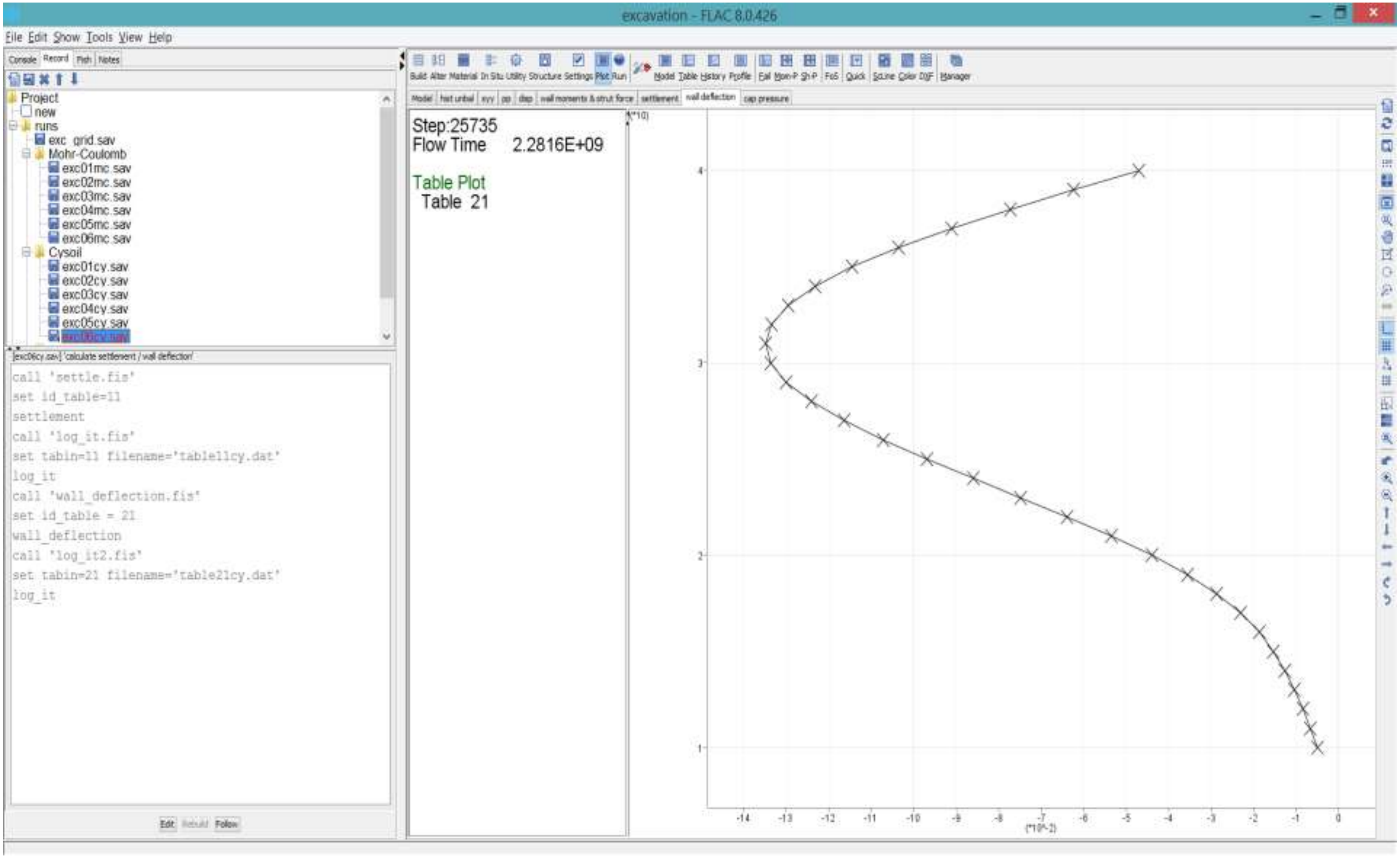
Step 5cy Repeat Steps 5-1 and 5-2 to excavate 2m. Save the state as exc04cy.sav.



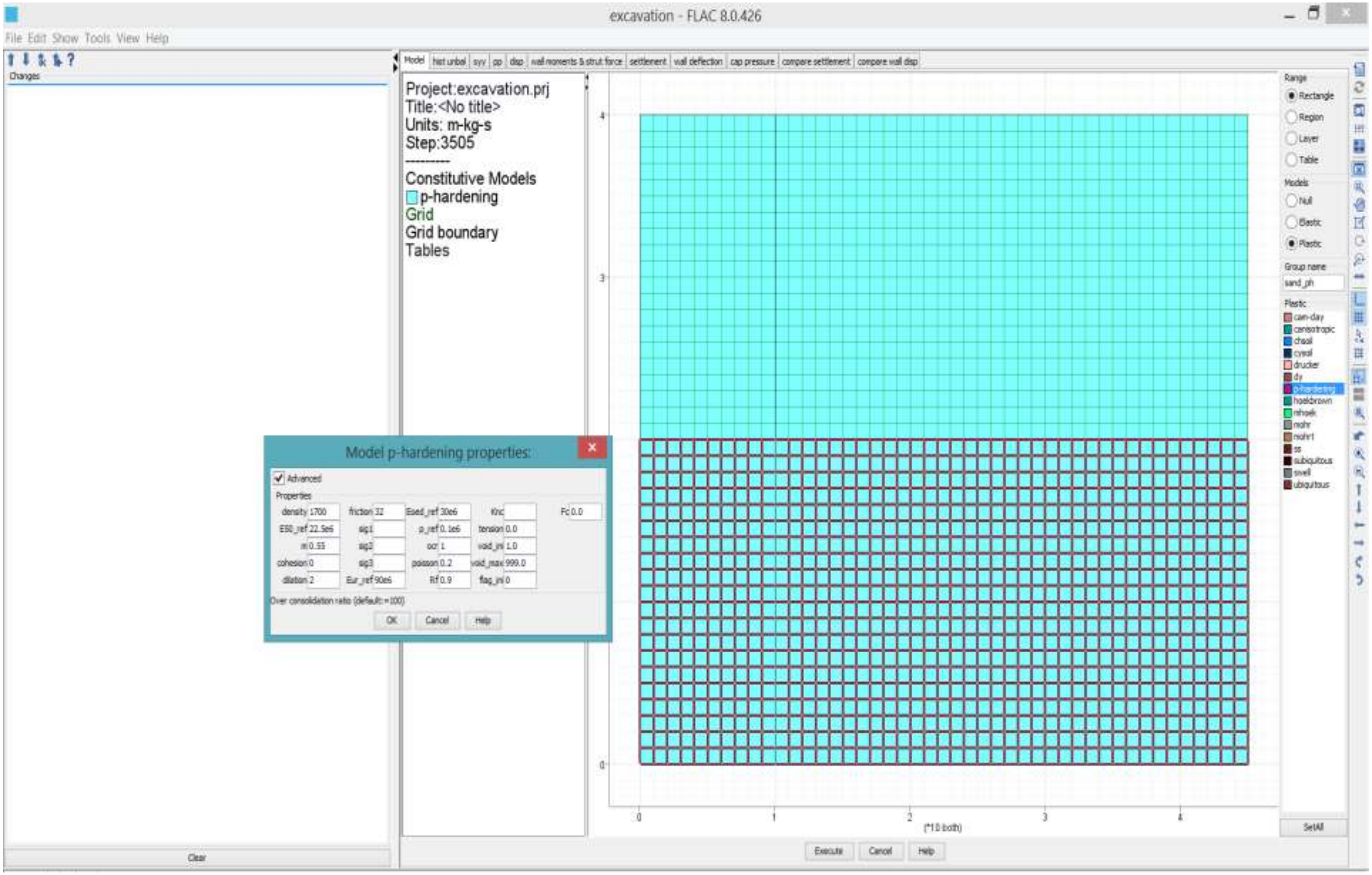
Step 6cy-1 Repeat Steps 6-1 to 6-6 to excavate to 10 m. Save the state as exc05cy.sav.



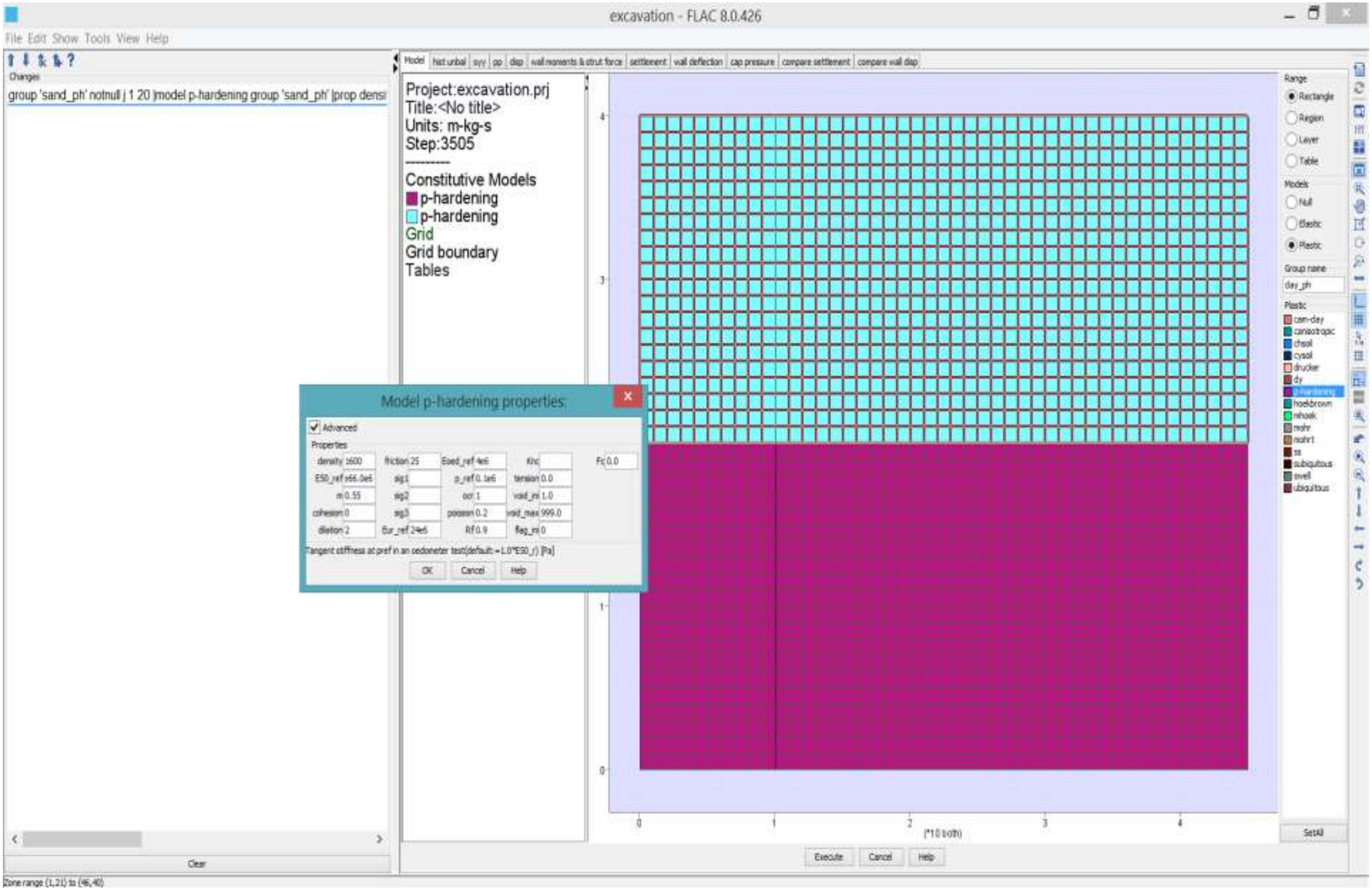
Step 6cy-2 Calculate surface settlement using SETTLE.FIS and store the results in table11cy.dat using log_it.fis. Save the state as exc06cy.sav.



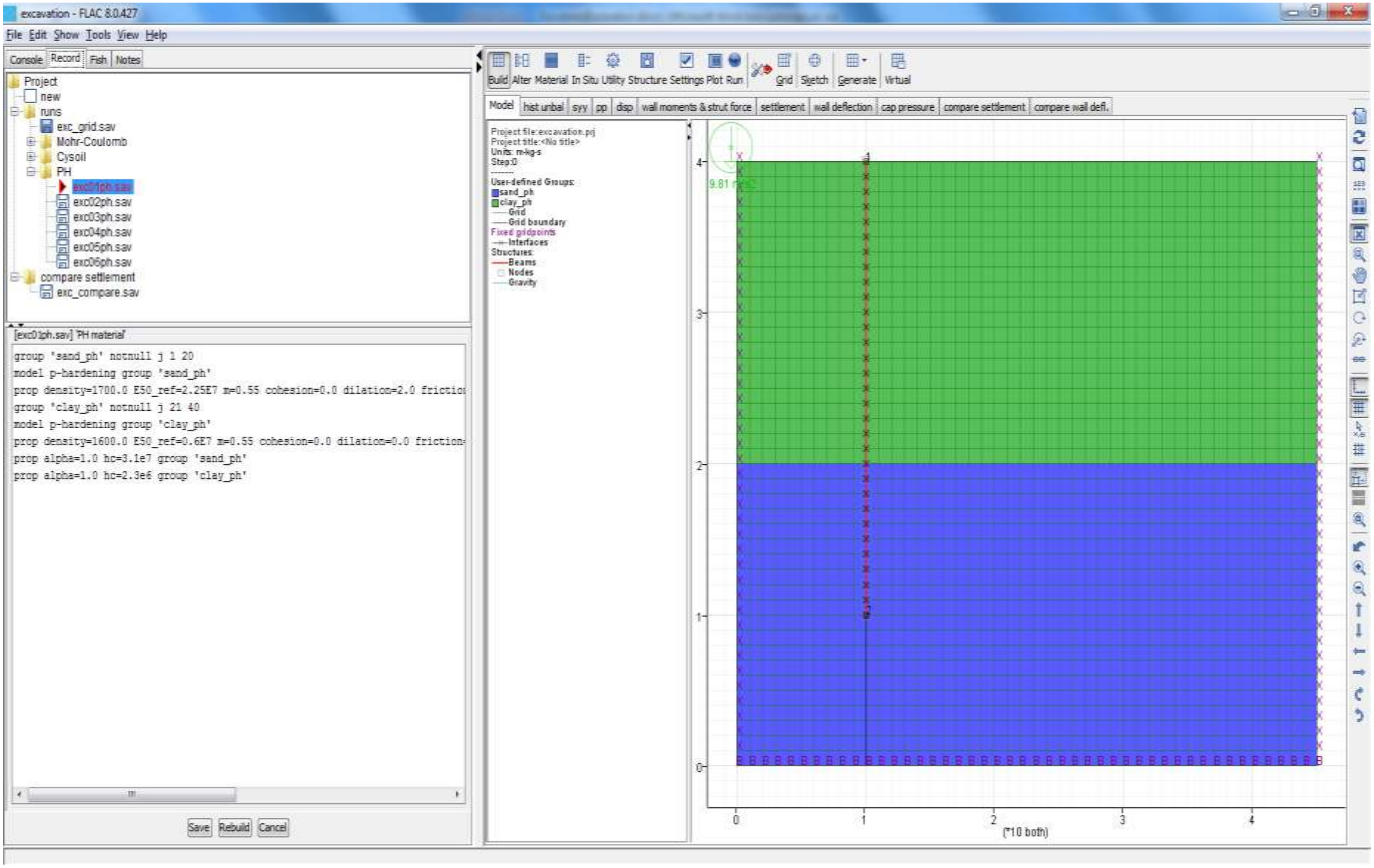
Step 6cy-3 Calculate wall deflection using wall_deflection.fis.FIS and store the results in table21cy.dat using log_it2.fis.



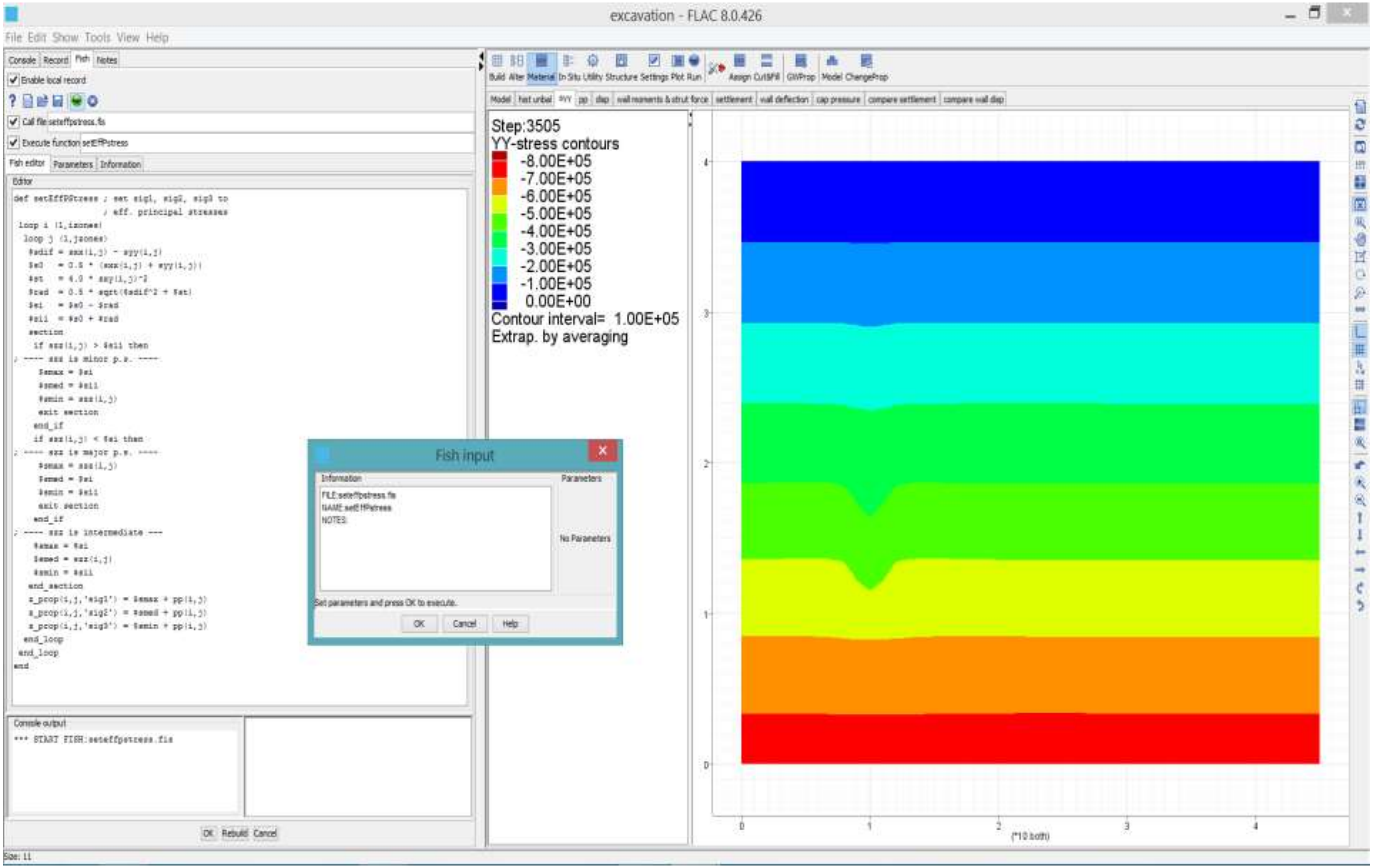
Step 2ph-1 Create a third branch using the same procedure as in Step 2cy-1. Then, enter the [Material]/[Model] tool, select the p-hardening Model, assign the group name sand_ph, and drag the mouse over zones from y=0 to y=20. Enter the ph properties for sand.



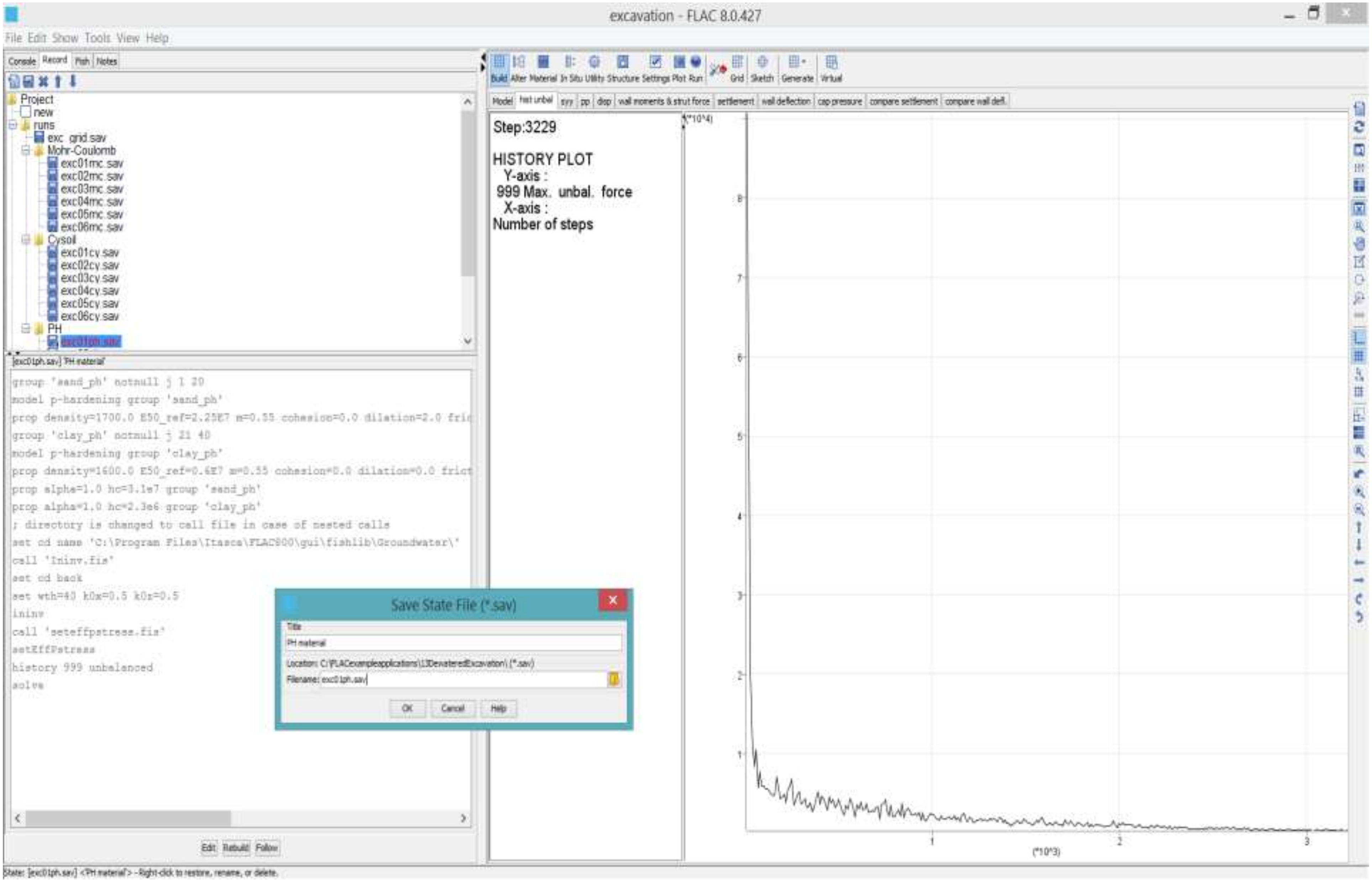
Step 2ph-2 Assign the group name clay_ph, and drag the mouse over zones from y=20 to y=40. Enter the ph properties for clay.



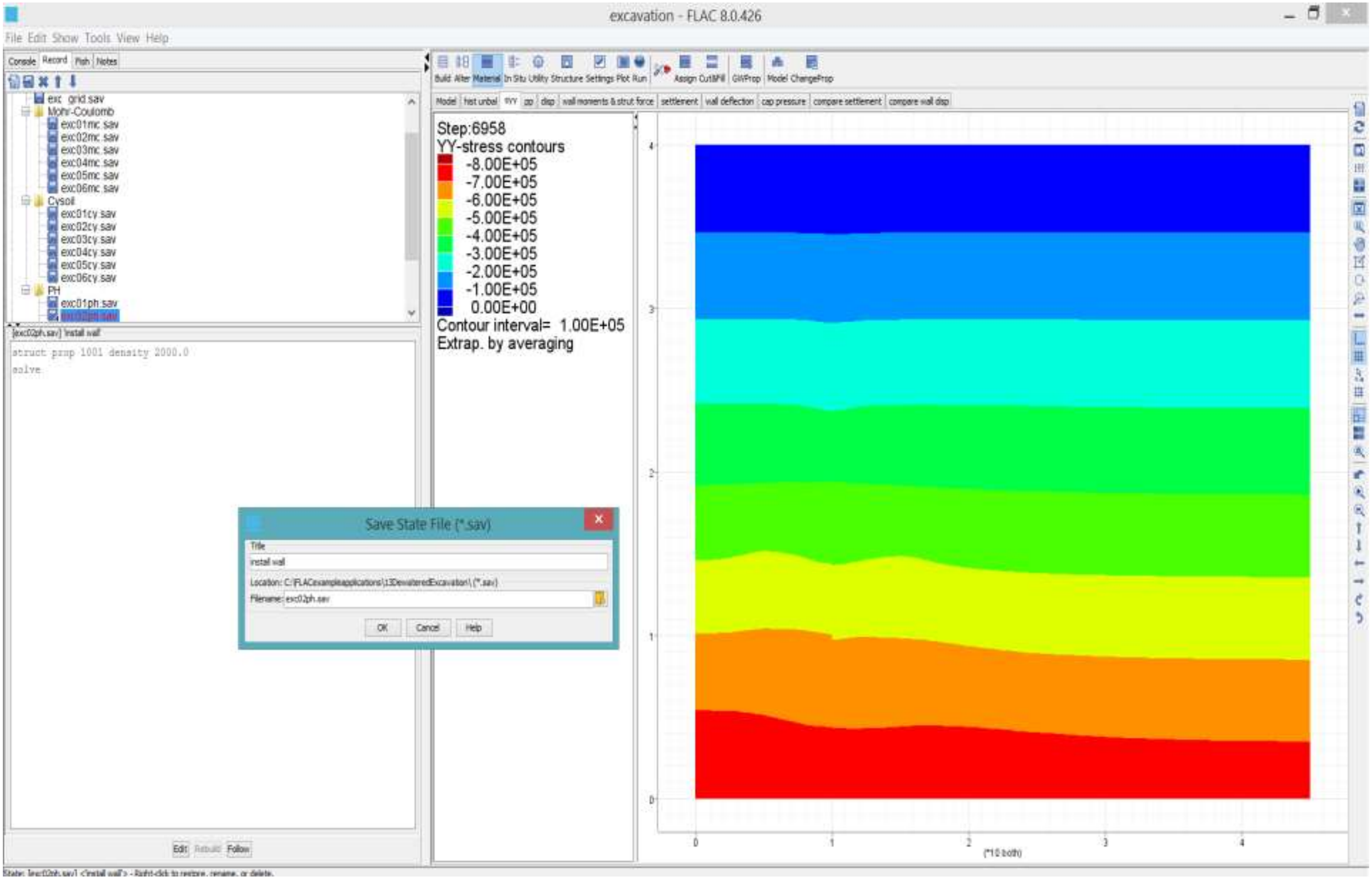
Step 2ph-3 In the [Record] pane add the commands: **PROP alpha=1.0 hc=3.1e7 group 'sand_ph'** and **PROP alpha=1.0 hc=2.3e6 group 'clay_ph'** Press [Rebuild] to re-execute the commands in this branch.



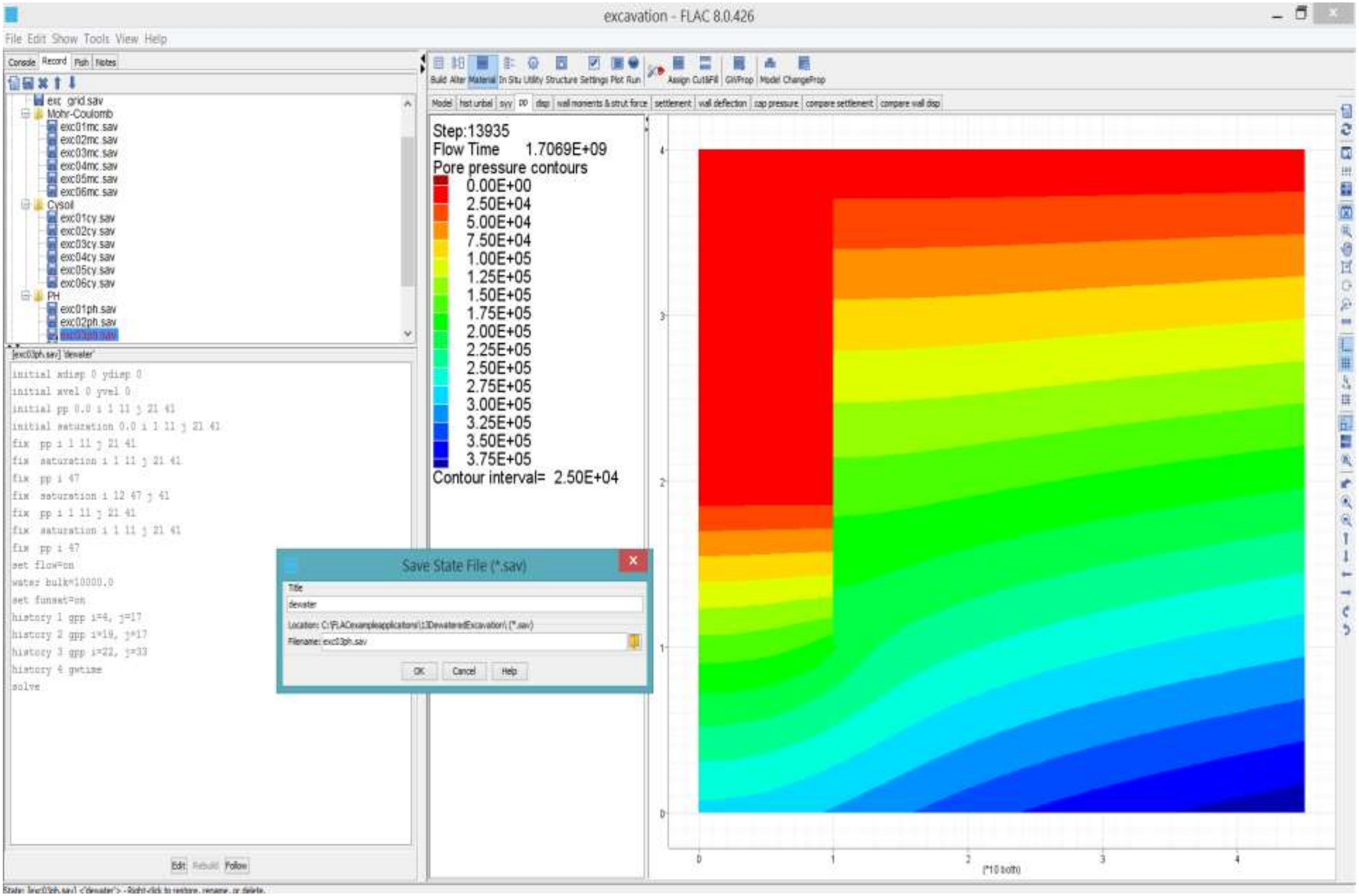
Step 2ph-4 Execute the ininv.fis function in the same manner as Step 2cy-4. Then, enter the [Fish] editor pane and execute setEffPstress.fis to assign the PH model properties: sig1, sig2 and sig3.



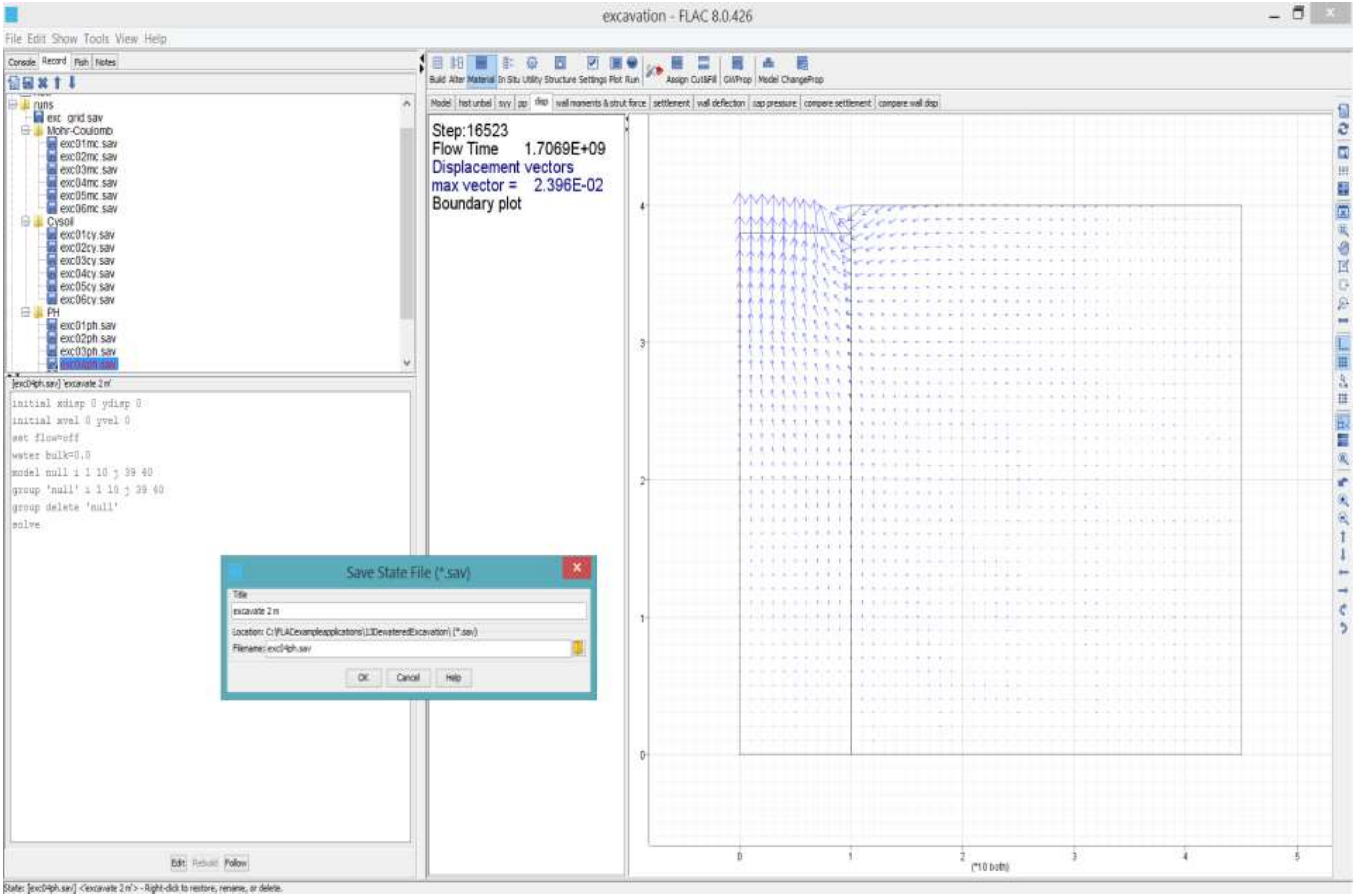
Step 2ph-5 Calculate the equilibrium state in the same way as Step 2cy-6 and save the state as exc01ph.sav.



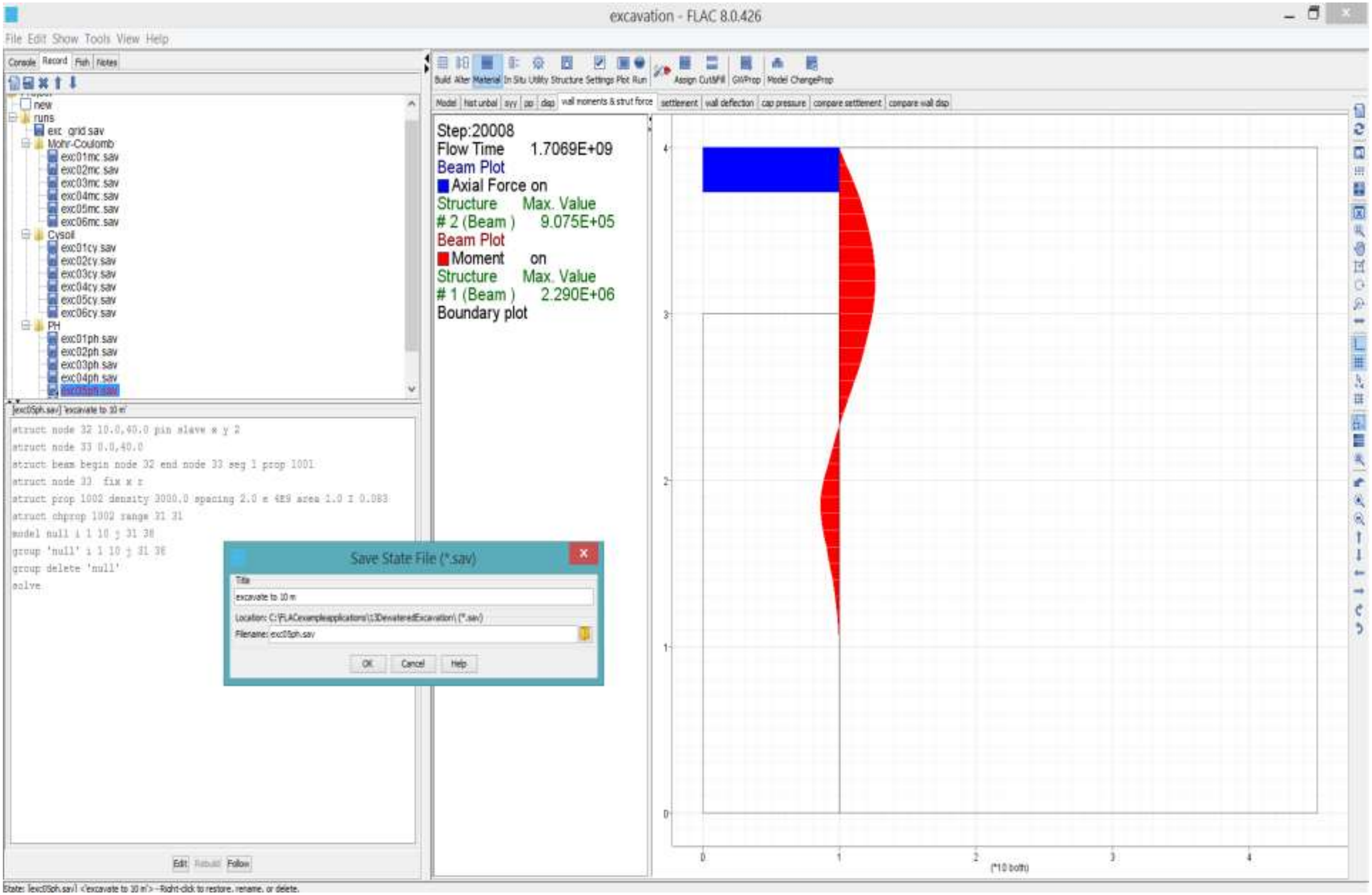
Step 3ph Repeat Step 3cy to calculate the equilibrium state with the wall. Save the state as exc02ph.sav.



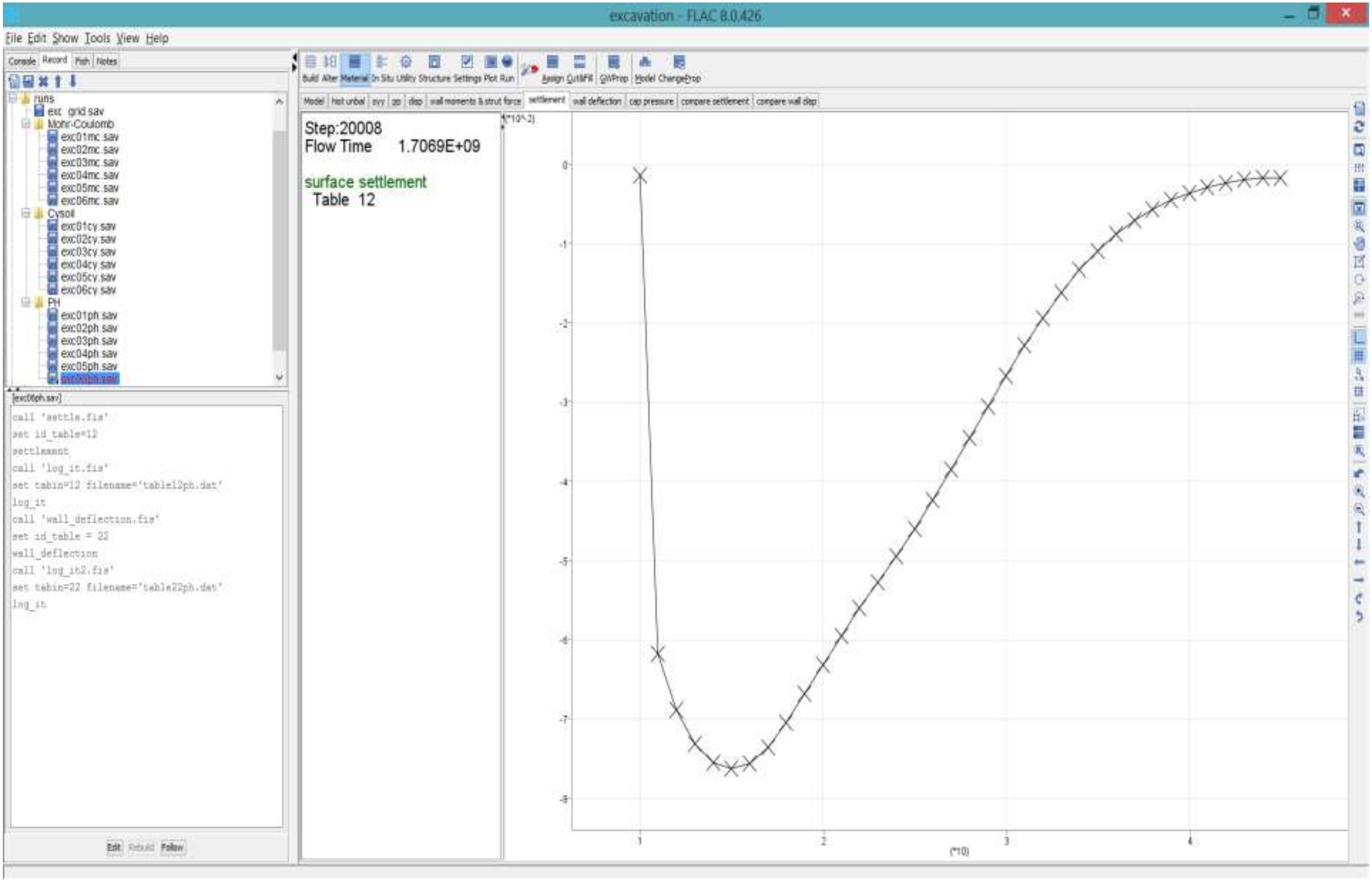
Step 4ph Repeat Step 4cy to dewater the excavation. Save the state as exc03ph.sav.



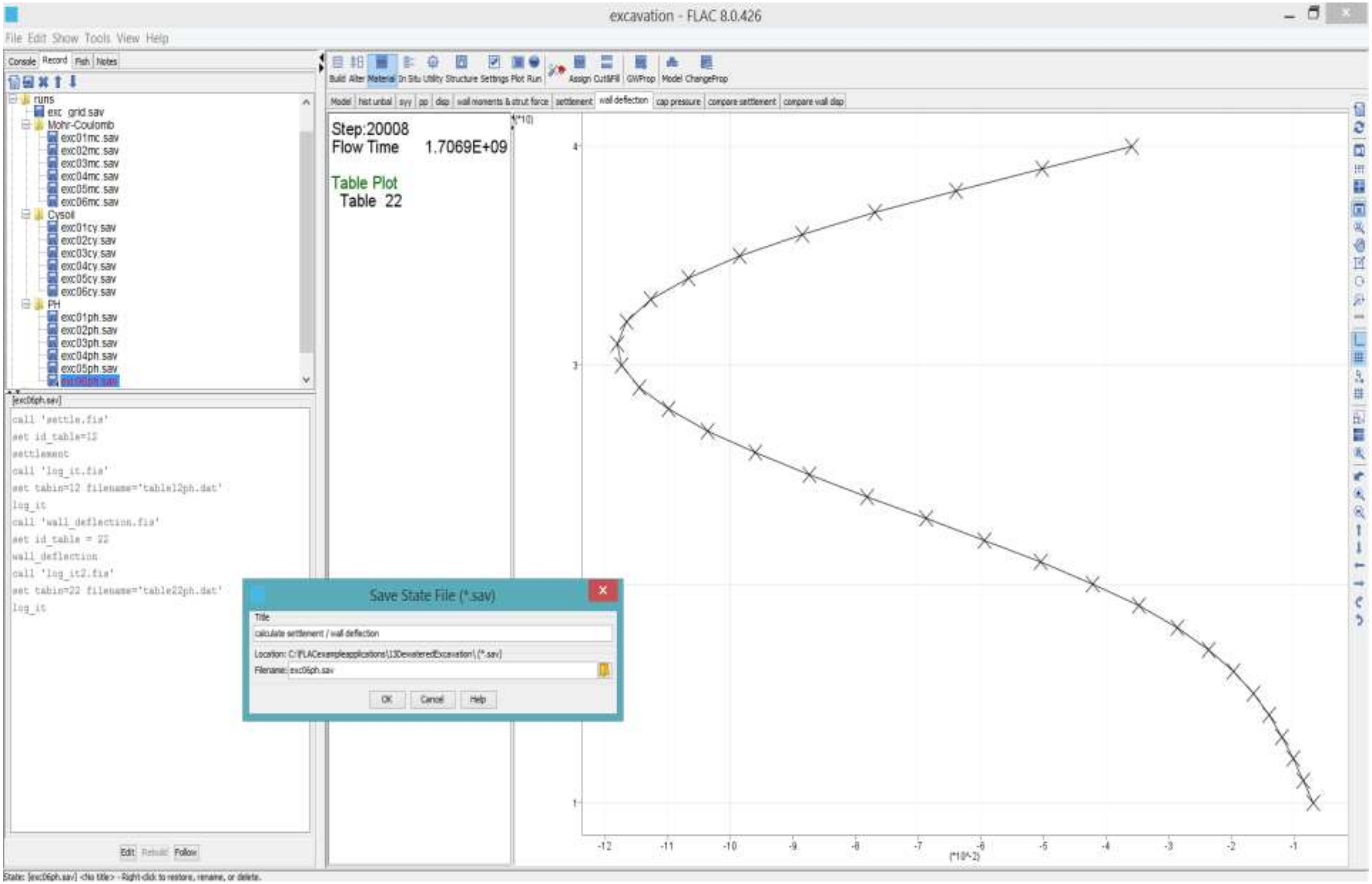
Step 5ph Repeat Step 5cy to excavate 2m. Save the state as exc04ph.sav.



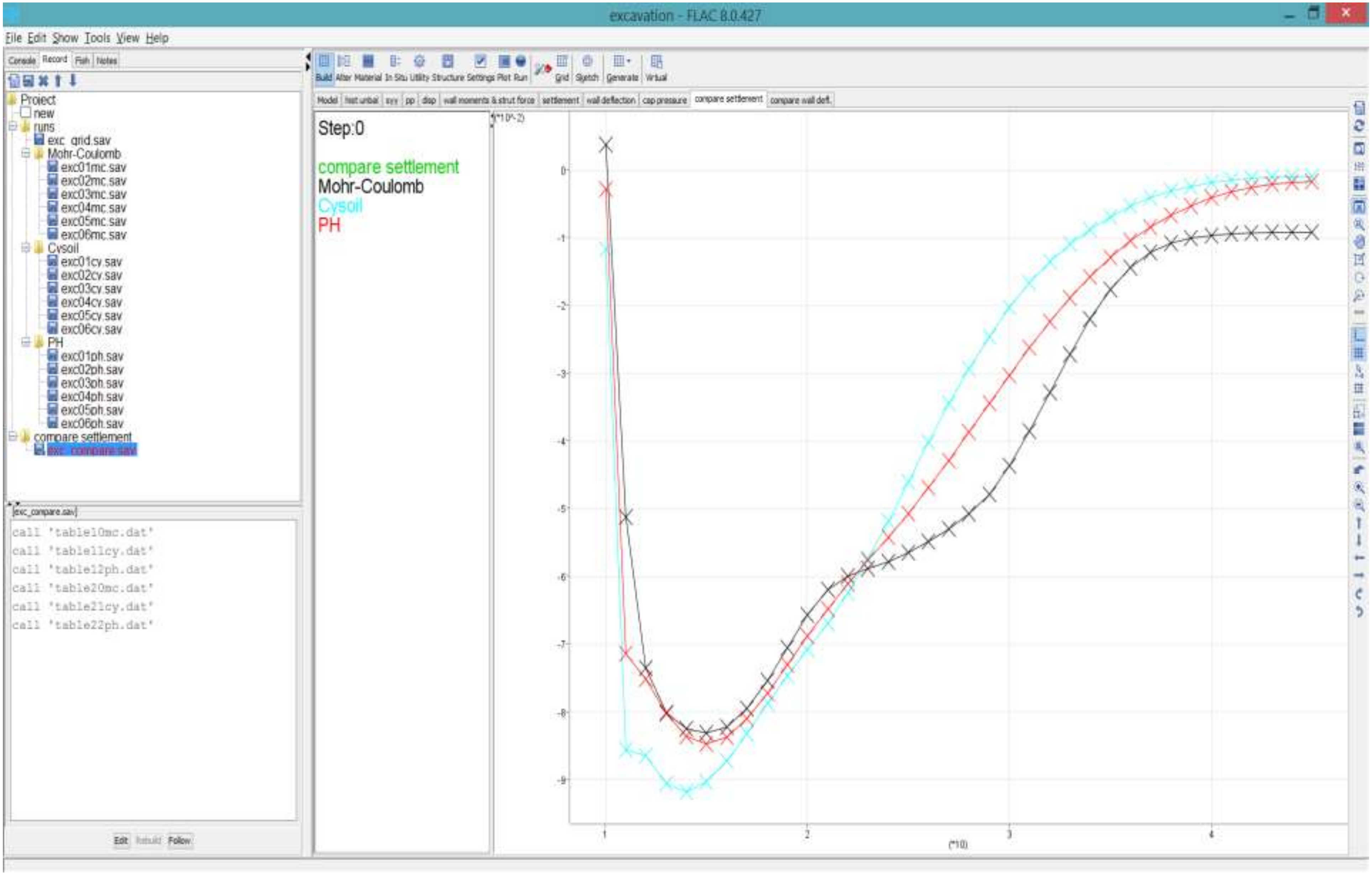
Step 6ph-1 Repeat Step 6cy-1 to excavate to 10 m. Save the state as exc05ph.sav.



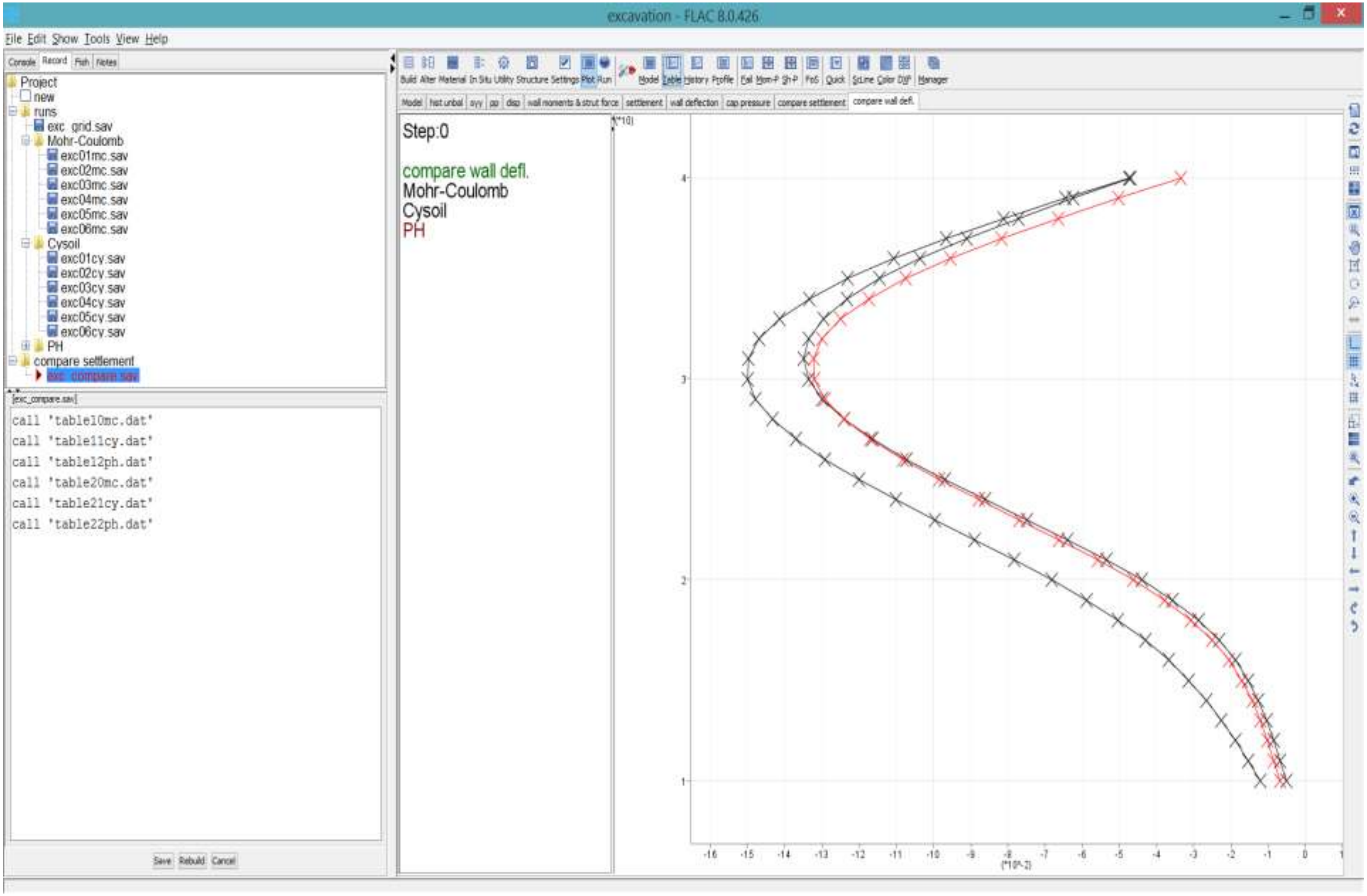
Step 6ph-2 Calculate the surface settlement in the same way as Step 6cy-2. Store the results in table12ph.dat.



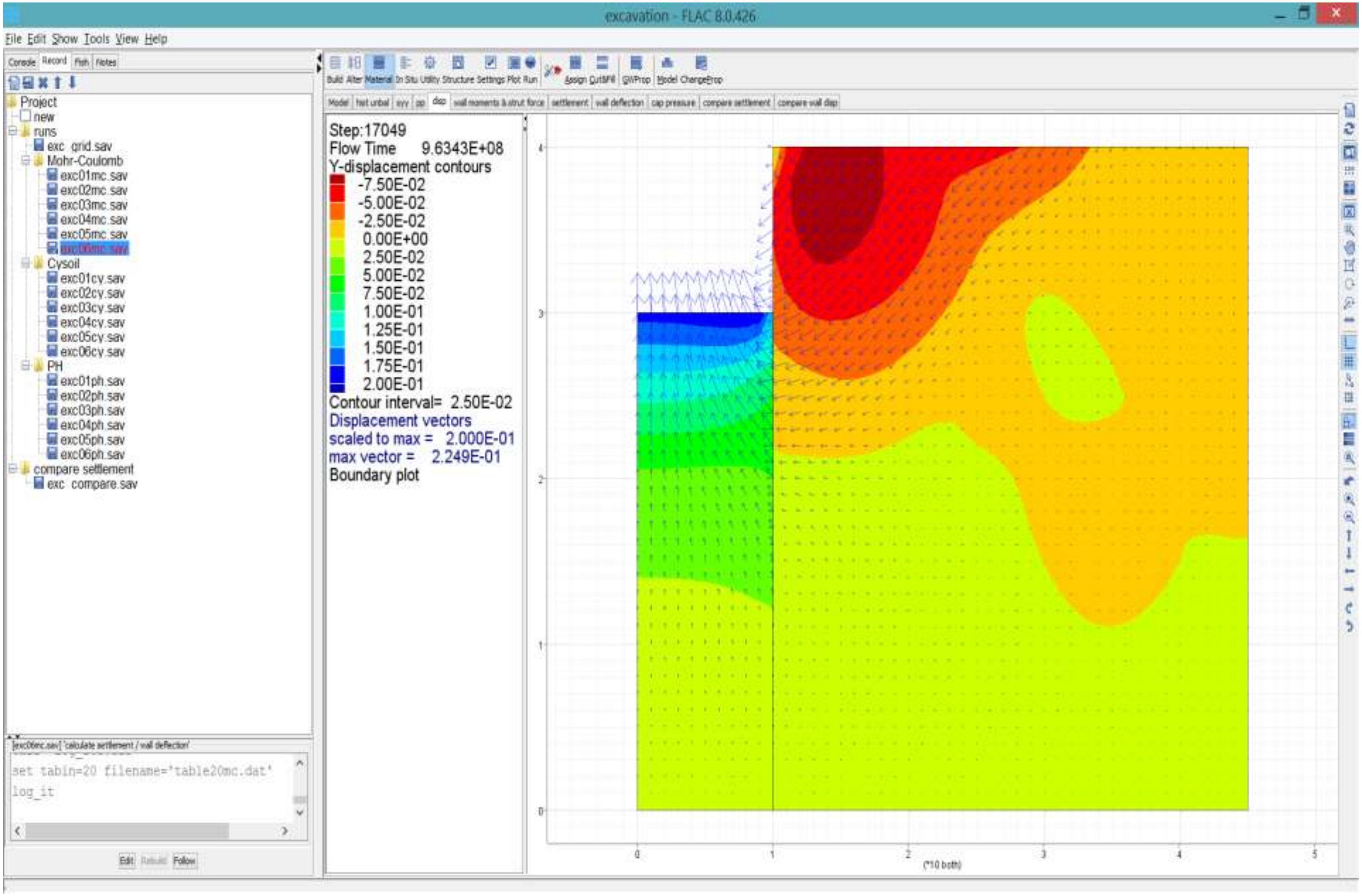
Step 6ph-3 Calculate the wall deflection in the same way as Step 6cy-3. Store the results in table22ph.dat.



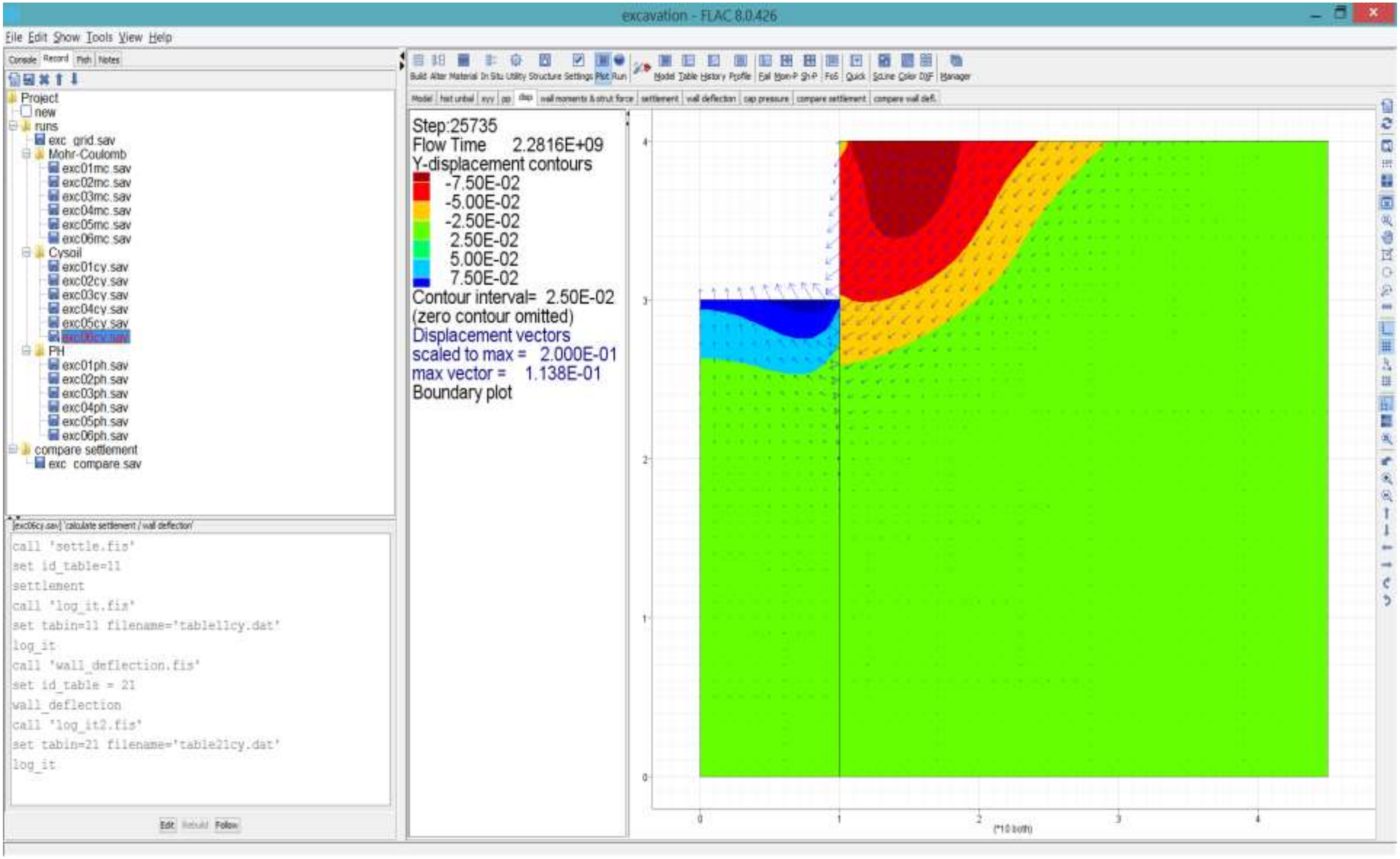
Step 7-1 Compare settlements from the three runs by calling in the table plot files using the [Utility]/[Call] tool.



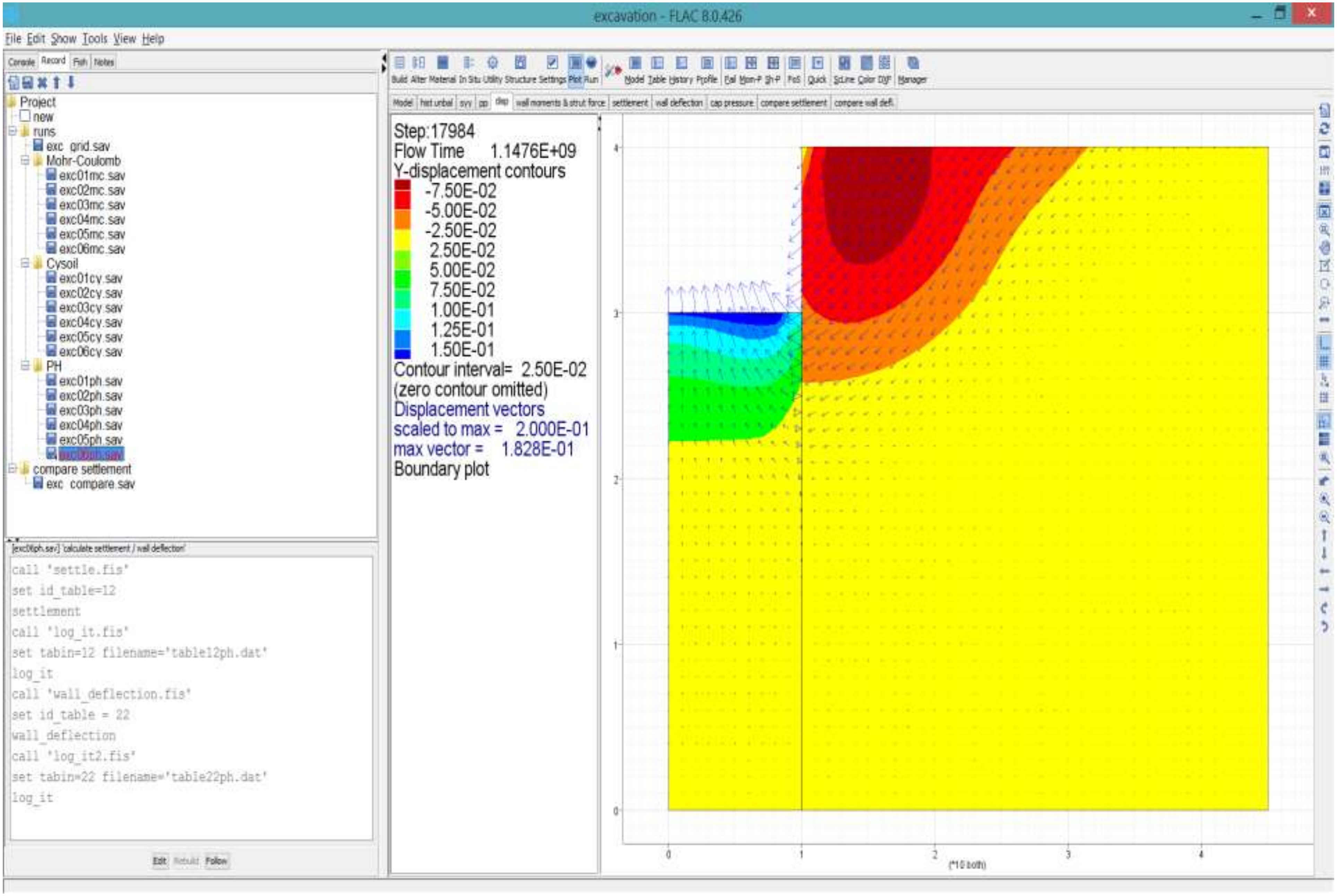
Step 7-2 Compare the wall deflection from the three runs by calling in the table plot files using the [Utility]/[Call] tool.



Step 7-3 Plot displacement vectors and y-displacement contours to show heave in excavation for Mohr-Coulomb material.



Step 7-4 Create a similar plot for Cysoil material. Heave is considerably lower primarily attributed to stress-dependent elastic moduli and stiffer unloading response of Cysoil material.



Step 7-5 Create a similar plot for PH material. Results are similar to the model with Cysoil material.