Linear Elasticity Tutorial 2:

To showcase the usage of Linear elasticity, we shall discuss here an example of a 2D bar, which bends under its own load. The bar 5×1 m^2 in area is made up of material with $\rho = 8 \times 10^3$, $E = 200 \times 10^9$, and $\nu = 0.3$. Contrary to tutorial 1, now both ends of the bar are clamped.

Step 1: Preprocessing

First step in a PSD simulation is PSD preprocessing , at this step you tell PSD what kind of physics, boundary conditions, approximations, mesh, etc are you expecting to solve.

In the terminal `cd` to the folder `\home\PSD-tutorials\linear-elasticity` . Launch `PSD_PreProcess` from the terminal, to do so run the following command.

```
PSD_PreProcess -problem linear-elasticity -dimension 2 -bodyforceconditions 1 \
-dirichletconditions 2 -postprocess u
```

After the `PSD_PreProcess` runs successfully you should see many `.edp` files in your current folder.

What do the arguments mean ? `-problem linear-elasticity` means that we are solving linear elasticity problem, `-dimension 2` means it is a 2D simulation, `-bodyforceconditions 1` with body force; `-dirichletconditions 2` says we have two Dirichlet border; and `-postprocess u` means we would like to have ParaView post processing files.

Since basic nature of both the problems (the one from tutorial 1 and 2) is same the almost the same command for preprocessing used in previous tutorial 1 is used here. The only difference,is that an additional Dirichlet condition needs to be supplied, notified to PSD by `-dirichletconditions 2`. To provide Dirichlet conditions of the left clamped end ($u_x = u_y = 0$) in `ControlParameters.edp` set `Dbc0On 2`, `Dbc0Ux 0.`, and `Dbc0Uy 0.`. Similarly, for the right end set variables `Dbc1On 4`, `Dbc1Ux 0.`, and `Dbc1Uy 0`. Each one of these is a clamped border respectively labeled as 2 (`Dbc0On 2`) and 4 (`Dbc1On 4`) in the mesh `../Meshes/2D/bar.msh`.

Just like the previous tutorial the input properties E, ν should be mentioned in `ControlParameters.edp`, use `E  = 200.e9`, and `nu = 0.3;`. The volumetric body force condition is mentioned in the same file via variable `Fbc0Fy -78480.0`, i.e ($\rho * g = 8.e3 * (-9.81) = -78480.0$). One can also provide the mesh to be used in `ControlParameters.edp` , via `ThName = "../Meshes/2D/bar.msh"` (*note that mesh can also be provided in the next step*) .In addition variable `Fbc0On 1` has to be provided in order to indicate the volume (region) for which the body force is acting, here `1` is the integer volume tag of the mesh.

Step 2: Solving

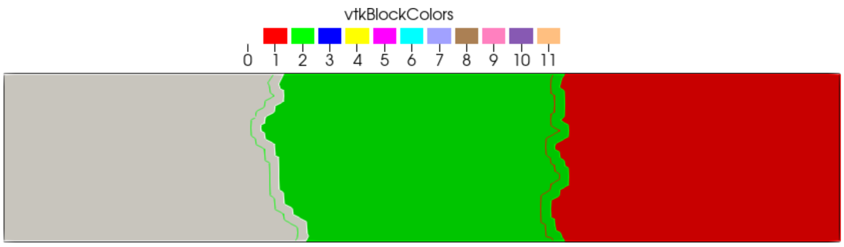
As PSD is a parallel solver, let us use 3 parallel processes to solve this 2D bar case. To do so enter the following command:

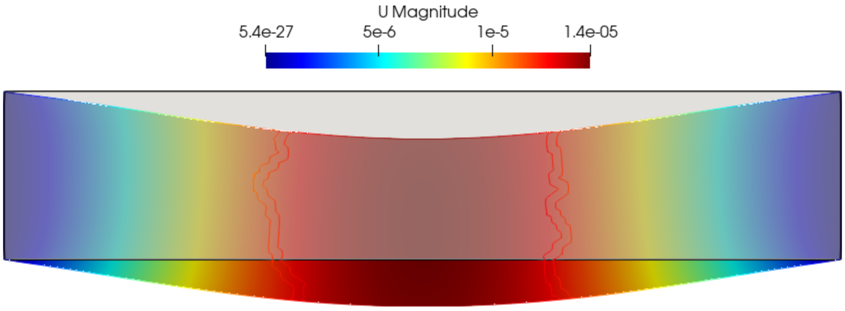
```
PSD_Solve -np 3 Main.edp  -mesh ./../Meshes/2D/bar.msh -v 0
```

Here `-np 3` denote the argument used to enter the number of parallel processes (MPI processes) used while solving. `-mesh ./../Meshes/2D/bar.msh` is used to provide the mesh file to the solver. `-v 0` denotes the verbosity level on screen. `PSD_Solve` is a wrapper around `FreeFem++` or `FreeFem++-mpi`. Note that if your problem is large use more cores. PSD has been tested upto 13,000 parallel processes and problem sizes with billions of unknowns, surely you will now need that many for the 2D bar problem.

Step 3: Postprocessing

PSD allows postprocessing of results in ParaView. After the step 2 mentioned above finishes. Launch ParaView and have a look at the `.pvd` file in the `VTUs_DATE_TIME` folder.





You are all done with your 2D linear-elasticty simulation.

What else should you try to become an advanced user

- Try running the 3D problem. Keep in mind to rerun the `PSD_PreProcess` with `-dimension 3` flag and using the approprite mesh via `-mesh` flag with `-PSD_Solve`. It goes without saying you will need to adjust the direchlet border lables in `ControlParameters.edp`.
- Since gravity is the main force involved in the problem, try redoing the test with diffrent graviational constant. Imagine, you wish to know how the test would compare if performed on Moon and Jupiter. The only thing that will change now is the gravitational pull, for Moon $g = 1.32$ and for Jupiter $g = 24.79$. To perform the moon test simply change `Fbc0Fy -10560.0` in `ControlParameters.edp` and redo step 2 and step 3. Similarly, for the Jupiter test `Fbc0Fy -198320.0` in `ControlParameters.edp` and redo step 2 and step 3.
- Optionally try using `-withmaterialtensor` flag with `PSD_PreProcess`, and run the simulation. You are encouraged to have a look at `ControlParameters.edp` and `VariationalFormulations.edp` file produced with `-withmaterialtensor` flag and without this flag.
- Add `-sequential` flag to `PSD_PreProcess` for sequential solver, but remember to use `PSD_Solve_Seq` instead of `PSD_Solve` and no `-np` flag.

```
PSD_PreProcess -problem linear-elasticity -dimension 2 -sequential \
-bodyforceconditions 1  -dirichletconditions 2 -postprocess u
```

```
PSD_Solve_Seq  Main.edp  -mesh ./../Meshes/2D/bar.msh -v 0
```

- You are encouraged to time your the PSD solver and see if you have considerable gains when using more processes in parallel PSD or when comparing a a sequential solver with a parallel one. To time the solver use `-timelog` flag during `PSD_PreProcess`.
- You are encouraged to use more complex meshes for this same problem, but do not forget to update the `ControlParameters.edp` file.