Application of Virtual Element Methods for geomechanical assessment of fluid storage in deep geological formations

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Renewable sources are considered key to decarbonize energy systems and reduce dependency on fossil fuels. However, despite the availability of solar energy and wind power, technologies relying on these sources are not fully viable yet due to their unstable and intermittent nature. Therefore, solutions to match the high-frequency variation of renewable energy production with the electricity demand are fundamental for energy transition. In this view, large-scale energy storage can provide means for balancing supply and demand, increasing energy security, promoting a better management of the grid and allowing convergence towards a low carbon economy. To this end, chemical storage is currently under investigation. Chemical storage implies transforming electrical power into chemical energy in the form of H2. One way to ensure large-scale storage of chemical energy is to use the storage capacity of deep geological formations. Furthermore, long-term CO2 underground storage is regarded as an essential mitigation option to reduce greenhouse gases in the atmosphere and contrast climate change. Temporary underground storage is also envisioned, as a strategy to efficiently match the quantity of captured CO2 and the quantity of CO2 that can be transformed CO2 into value-added fuels and chemicals. Thus it is evident that underground storage systems can play a fundamental role in the transition to a more sustainable energy future.

The goal of this research was to apply the recently formalized Virtual Element Method (VEM) to build 3D geomechanical models and address the safety issues associated to fluid storage in deep geological formations, namely rock integrity and compaction/expansion due to fluid withdrawal/injection causing ground level subsidence/rebound. The advantage of using VEM mainly resides in their versatility to reproduce complex geometries while maintaining a certain computational "simplicity" without losing solution accuracy.

The development of the project required that knowledge and skills on numerical analysis were merged with competences and experience gained on fluid storage in underground formations. The main tasks were (1) the validation of the 3D VEM library (*GeDim+VemElast*) developed for the solution of boundary differential problems that describe the stress-strain behavior of deep formations subject to underground storage operation in the linear-elastic-domain; (2) the integration of stratigraphic and fault surfaces deriving from seismic interpretation within the tetrahedral discretization process of the investigated geological volumes, which was achieved by developing and implementing an effective triangulation algorithm implemented; (3) the grid construction using simplexes (tetrahedral cells), which also represented the preparatory step for the construction of generic polyhedral grids obtained through gluing algorithms.

The libraries necessary to generate the models were coded in an opensource environment (*QTCreator + CMake + MinGW*) and integrated in a unitary product which support the cross-compiling between MS Windows and GNU/Linux. Extensive validation tests of the new model to calculate compaction/expansion due to fluid withdrawal/injection and corresponding ground level subsidence/rebound in the linear-elastic domain were performed. First simplified cases were considered. Then, tests on realistic models of the Italian Adriatic offshore and of the Po Plain panorama. The simulation results proved very satisfactory and consistent with the ones obtained by a commercial FEM solver dedicated to geomechanical simulations and typically used in the oil&gas field.

Validation tests were mainly performed in the linear-elastic domain because the technical literature consistently shows that the formations behave elastically. However, tests were also performed in the elasto-plastic domain. Convergence issues highlighted the need to modify the iterative algorithm implemented to solve the constitutive problem in order to obtain consistent results under any investigated scenario.

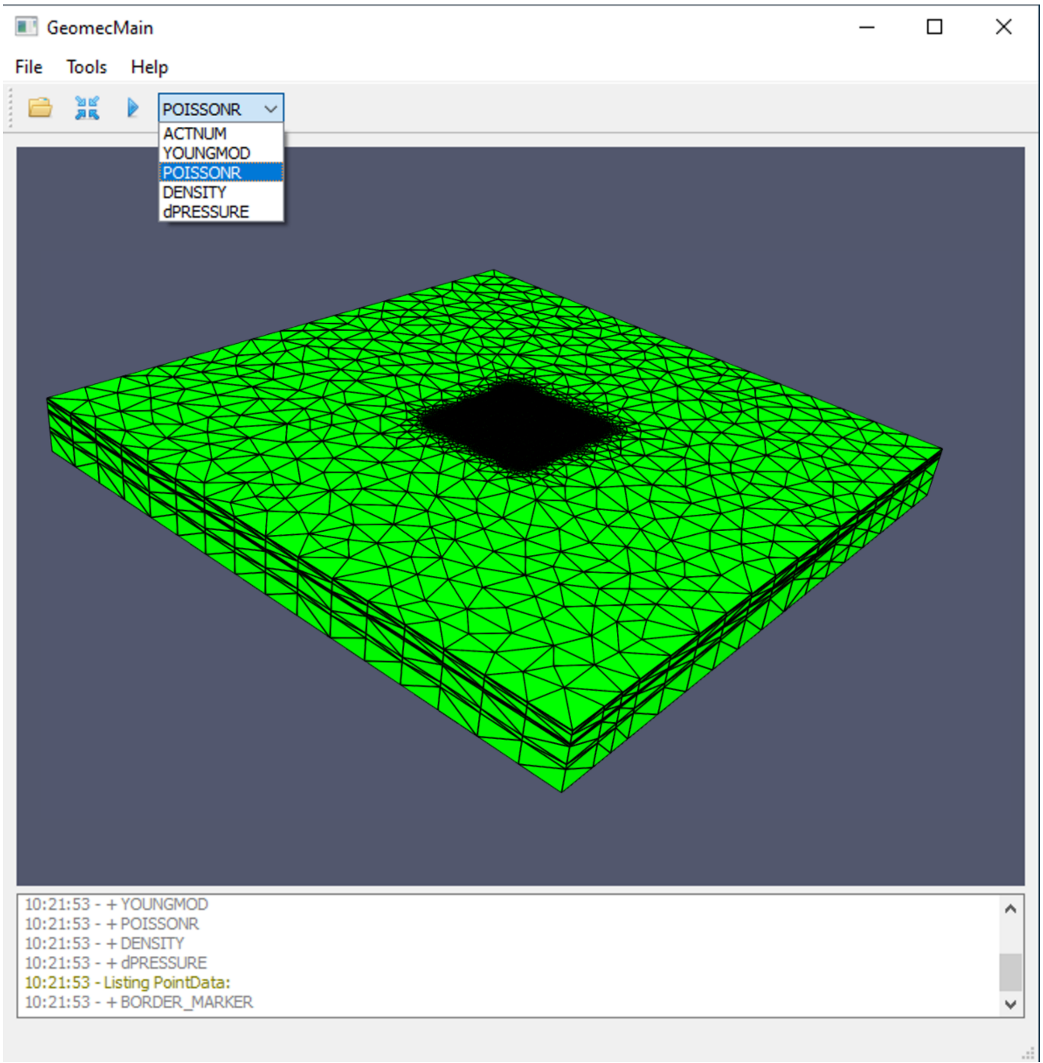

Figure 1: example of unstructured grid for VEM simulations uploaded in the developed Main Application