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Virtual elements for representation of faults, cracks and hydraulic fracks in dynamic flow simulations

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Discrete fault representation at reservoir level in flow and transport modelling is generally a complex task, since a suitable refined spatial fault discretization is required conforming to grid convergence criteria of the chosen numerical simulator. Within the scope of the present study a concept for discrete fault integration into reservoir-scale dynamic models was developed taking into account variable fault geometries without modification of the initial gridding scheme.

Fault discretization is fully managed by the introduction of so called virtual elements into the model following the discrete fault geometry and allowing for arbitrary parameterization and inter-connectivity. A further advantage of the chosen approach is the feature of a separate description of the generally low-permeable fault core and high-permeable damage zone taking into account a specific thickness and hydraulic conductivity.

The workflow is separated into multiple steps starting with reading of the initial reservoir simulation structured hexahedron grid constructed in a pre-processing software package (e.g. Schlumberger Information Services Petrel) and its storage in an adapted data structure representing element ids, corner coordinates, centres and volumes determined as discussed by Grandy (1997).

Using the element coordinates virtual elements are being generated, while data on fault description is being read from the geological model through assigning an element thickness of choice. Fault inter-connections are calculated considering element coordinates based on the method of Greiner (1998) and stored in an adapted data structure representing each fault as a separate grid (local grid refinement). Further information required to start the simulation runs, such as element connection distances, volumes as well as interface areas to other lateral and horizontal neighbouring elements, are directly written in the simulator input files.

Since fault inter-connections are represented by two virtual elements (damage zone located left and right from the fault core), irregular and winding fault structures lead to the development of unstructured grids. For that purpose, the connections along a fault are ordered from the starting point neglecting the initial i, j, k-ordering of the reservoir-scale grid. A winding counter to track fault geometry changes to assign proper virtual element connections was implemented to suit this demand.

Coupled multi-phase flow simulations were undertaken to verify the virtual element concept developed. Application of this strategy in numerical simulations of CO_2 storage shows reasonable results with regard to pressure propagation and mass flow of brine displaced from deep storage formations into shallow aquifers through high-permeable discrete faults.

References

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