2.75 d finite element model of 3 d fracture network systems

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The grid generation method to be explained in this study has been developed to meet the needs arising in fluid flow simulation for fracture network systems. The case to be treated is the geothermal energy test site Soultz-sous-forêt in France. At a depth of 3500 m water is led through a domain of 165 ℃ that consists of seven main fractures in a porous rock. Geological analysis showed that these fractures can be regarded as planes which are not only intersecting each other at a high rate but as well frequently doing so with an extremely small angle. The aim for the simulation in this complex domain is to give an explicit scheme of the flow regime concerning fluid flow, tracer flow, and heat conduction by use of the finite element method. Therefore the fracture elements are described by quadrilateral 2 d elements and are connected to the surrounding geologic layer which are described by hexahedral 3 d elements. This procedure has the advantage to keep the unknown thickness of the fracture as a parameter and to reduce the disretization scale needed for stability and correctness of the simulations.

Consequently, the mesh generation method is required to divide a convex 3 d domain split up into convex subdomains into hexahedra. It is especially asked to provide a high finite element mesh quality near the fractures as that is the region dominated by the simulated processes and to ensure numerical stability for the elements constitutionally containing the extremely small angles. Furthermore simplicity, uniqueness, and robustness are demanded.

A closer look at the hexahedral meshing methods available shows: The advancing front method and its family for 3 d hexahedral meshing do not provide uniqueness and suffer from a lack of closure procedures. Blocking methods are not recommended due to manual effort needed. Finally, tetrahedral meshing followed by hexahedration cannot improve the mesh quality which appears at the triangulation, but fulfills any of the other requirements stated above, so that it is taken as the starting point for developing the new mesh generator.

The method can be trisected. At first a topological analysis of the domain takes place. The fractures divide the whole domain into subdomains and divide each other into plane segments. Each subdomain is defined by the fracture plane segments that compose its boundary. At the second step each subdomain is treated separately. For each subdomain all related boundary plane segments are picked and this convex hull is shrinked into the subdomain. It divides the subdomain into a core and a skin part. The core has the same shape as the original subdomain but has moved away from the fracture boundaries. The skin, the 3 d space inbetween can be split into a parallelepiped at each vertex, a prismatoid at each edge and once more a prismatoid at each plane segment. The vertex parallelepiped can easily be hexahedrally meshed. The plane segment prismatoid is meshed by a 2d triangulation of the polygonal basis, followed by a quadrangulation and a final hexadration via projection of the 2d quadrilaterals. For the triangulation of the basis polygon points are introduced on the line segments. For consistency reasons these points are included in the meshing of the edge prismatoids. In the final third step, the core is meshed. This takes place with a 3 d Delaunay tetrahedration being followed by a Taniguchi hexahedration.

By this way, the quality of the hexahedra neighboring the fractures is improved compared to a pure tetrahedration with a hexahedration. Two questions remain. First: How can the numerical stability be raised for those finite elements containing constitutionally small angles? Second: If the zone mainly affected by the physical processes to be simulated is the close vicinity of the fractures, do the core parts contribute at all?

Those fractures that intersect under an exceedingly small angle are considered to produce an extended zone of intermediate porosity. To all elements close to the intersection line this porosity is given. In doing so, on the one hand, a more realistic physical model ist obtained, and on the other hand the numerical stability of these less well shaped elements is improved.

For the core parts of the subdomains it is reasonable to assume steady state conditions. The mesh may be reduced to the skeleton formed by the skin parts of all subdomains which is called a 2.75 d mesh. This offers a possibility to simplify and accelerate the simulation.

As parameters to be defined during the grid generation process are left the size of the hexahedral elements, the number of element layers in the skin parts, and the distribution of the porosity at the sharp angled intersection zones. Furthermore it is left open whether the resulting mesh is one that solely consists of 2 d fracture elements (so called 2.5 d simulation) for the simulation of fluid or tracer flow, a 2.75 d mesh for the simulation of the former and of heat flow, or a full 3 d hexahedral mesh.

In order to illustrate the method the applications of it at the Soultz-sous-forêt test case is presented.