Pressure-Displacement Coupling in Poroelasticity. Further Studies on a Stable Finite Volume Formulation

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ABSTRACT

This paper further investigates the numerical behaviour of a finite volume technique using staggered grids for solving poroelasticity problems [1]. Attention is given to the well-known drawback of pressure instabilities, which arises in certain conditions, as in low permeability media, fast transients and undrained conditions. In practical applications, as in petroleum reservoir simulation, two independent software are used, a finite volume one for the fluid flow and a finite element for the rock mechanics. This confers to the whole scheme the required stability, since finite volume techniques are able to solve the fluid flow with no pressure oscillations and the standard Galerkin finite element method suffices for the solution of the rock mechanics. It is clear that this strategy is not practical, since it requires two different methods, perhaps different grids with the necessary data interpolation among them. Therefore, it is imperative to have research efforts for developing numerical approaches employing a single numerical method for the solution of poroelasticity problems.

Following this route, there is a large amount of literature targeting the solution of this coupled problem using finite element for both physics, investigating deeply the reason for the appearance of pressure instabilities, since it is well known, that standard Galerkin produces oscillatory pressure solutions, requiring more sophisticated mixed finite element methods and other strategies to obtain a stable solution. Locking, equal order of interpolation for pressure and displacement, violation of the LBB condition has been claimed as the reason for those instabilities [2]. Despite the origin of instabilities, stabilization techniques need to be devised in order to obtain a solution, and this is a rich field of research among the finite element practitioners, revealing, however, that the implementation of such stabilizers ended up in more complex and time consuming numerical schemes.

It has been shown that finite volume techniques, enforcing mass conservation and forces balance in a discrete level, is a viable route for the solution of the coupled fluid flow and geomechanics. However, stabilization techniques are still required if pressure and displacement are co-located on the computational grid. Fortunately, since the stabilization technique is funded on physical grounds, it is straightforward derived and renders to the method robustness [3]. If a fully stable solution is devised, with no need of stabilization techniques at all, it has also been shown that the use of staggered grids is the answer [1]. This paper recapitulates the main features of a stable finite volume method for poroelasticity employing staggered grids, pointing out the similarities of the pressure-displacement coupling in poroelasticity with the pressure-velocity coupling in the Navier-Stokes equations. Additional results are shown for the double layer Therzaghi’s problem, demonstrating the robustness of the method for a wide range of non-homogeneous grids.

REFERENCES