ROBUST TRACKING OF FREE SURFACE IN THE PRESENCE OF CURVED VESSEL WALLS

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Many marine, reservoir and waterways flows exhibit complex free-surface motion, which is nonetheless limited in amplitude. Such situations justify the use of deforming mesh and the mixed Lagrangian-Eulerian approach, in the form of an ALE or space-time method. In order to follow the motion of the mesh boundary coinciding with the free surface, a kinematic condition needs to be discretized and solved. The usual form of such a condition is an equation for vertical elevation written over a lower-dimensional domain (e.g. channel bed). Because of its hyperbolic nature, it is well known that solution of such equation requires stabilized rather than Galerkin formulations, such as SUPG or GLS.

We derive a generalized form of the elevation equation, and its stabilized GLS formulation, for cases where prescribed direction of surface node displacement is not uniformly vertical, and may in fact be taking place along curvilinear spines. The initial form was derived for space-time applications [1] and limited to straight spine motion; recent forms of the generalized elevation equation are suitable also for ALE and Lagrangian applications, and can handle surface node displacement along curvilinear spines.

The robust handling of the kinematic condition is coupled with a general elasticity-based mesh update technique, used to smoothly adapt the computational mesh in the interior of the domain to given boundary displacements. The fluid flow is governed by the incompressible Navier-Stokes equations, again discretized using a GLS finite element formulation. The three equation systems (elevation, mesh update, fluid flow) are solved in a loosely-coupled fashion, within the iteration loop required for the solution of non-linear flow equations. Within each iteration, each system is solved separately, using an iterative GMRES solver. It is the nature of the loosely-coupled approach that some coupling terms are treated explicitly; for the applications considered, no difficulties in the convergence of the overall solution process were observed.

Our approach enables us to simulate nonlinear sloshing in trapezoidal and semi-circular tanks, hydraulic jumps in spillways and trapezoidal channels with obstacles, and in the future, will allow the elevation equation to be used in cases involving ships with complex hull shapes.

References

[1] M. Behr and F. Abraham, “Free Surface Flow Simulations in the Presence of Inclined Walls,” *Computer Methods in Applied Mechanics and Engineering*, v. 191, p. 5467–5483, 2002.