SUMMARY OF Ph.D. DISSERTATION

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Title

Extension of Poisson Solver and Coupled Analysis for Flexible Solid and Fluid based on GSMAC-FEM

Abstract

The rubber parts used in industrial products and the flexible bio-tissue such as the blood vessel, the heart valve, and the eyeball retina are easy to be deformed. Interaction between the flexible solid and fluid is the problem that computer load is big. In the present study, the small natural frequency of the flexible solid, the application of higher-order elements in fluid-solid strong coupling, and the necessity of dynamic analysis method of incompressible hyperelastic material suitable for low memory capacity and high speed computation are noticed. Then, the explicit computational method for analyzing fluid-solid coupled system is proposed on basis on GSMAC (Generalized-Simplified Marker And Cell) -FEM that is one of the velocity-pressure decoupled-type FEM used in the fluid analysis and the effectiveness is verified. The composition of this thesis and the knowledge in each chapter are shown as follows.

In chapter 1, the background and the purpose of the present study are described.

In chapter 2, lid-driven cavity flow can be sufficiently analyzed using the extended Poisson solver of GSMAC-FEM so that element shape and interpolation order are not limited. And the validity of the diagonal component method using higher-order pressure interpolation function and the simultaneous relaxation method for pressure nodes by using satellite elements are able to be confirmed. In two-dimensional lid-driven cavity flow, the combinations of the interpolation function that have good convergence for the simultaneous relaxation iteration, i.e. quadrilateral Q_2Q_1, triangular $P_1^+P_1$ or triangular $P_2^+P_1$ elements, are found. Though it is possible to also use mixed mesh consisting of quadrilateral Q_2Q_1 elements and triangular $P_2^+P_1$ elements, the advantage is not able to be fully shown in the analysis of cavity flow. By considering the result of two-dimensional analysis, the three-dimensional lid-driven cavity flow is sufficiently analyzed by using hexahedral Q_2Q_1, tetrahedral $P_1^+P_1$ or tetrahedral $P_2^{++}P_1$ elements. Therefore the extended Poisson solver is available to three-dimensional analysis.

In chapter 3, from the viewpoint of the equivalence of "the third invariant of deformation gradient is equal to one" and "the divergence of velocity is equal to zero", the computational method for analyzing the behavior of the incompressible hyperelastic material is proposed using not the velocity-pressure coupled-type FEM that has ever been used but the decoupled-type FEM. And the effectiveness toward to practical use is verified. Firstly, the simple deformation problem is analyzed by using Q_1Q_0, Q_2Q_1, $P_1^+P_1$, or $P_2^+P_1$ ($P_2^{++}P_1$) elements and the approximate solutions have good agreements with the exact solutions in static state. The volume of the solid is sufficiently preserved without the accumulation of the volume error because of the cycle-to-cycle self-adjustment method which is the feature of the velocity-pressure decoupled-type FEM. Secondly, stress-strain curves like S-letter are made by calculating the element-average values of elastic constants of the higher-order Mooney-Rivlin material in order to introduce the stiffening property of the high polymer material under large deformation.. Thirdly, the differences between various elements are compared in terms of the accuracy of solutions under the severe condition in compression block problem that has singularity is treated. Utilizing the linear interpolation function for displacement makes the accuracy of the pressure field worse on the outside near a singular point.

In chapter 4, the explicit computational method for fluid-solid coupled system is proposed based on ALE (Arbitrary Lagrangian-Eulerian) GSMAC-FEM in order to analyze the interaction of fluid and flexible rubber-like solid. The stability of time-marching is improved by satisfying the discretized equation for fluid-solid strongly coupled system in next time using the explicit iterative calculation. In order to verify the effectiveness for the problem that the fluid-solid interaction is large, two-dimensional vortex-induced vibration problem is analyzed about the interaction of vortices and elastic plate attached to rigid prism. Firstly, the case of the elastic plate made in Hookean elastic material is treated. Symmetric vortices arise from the rigid prism after the start of computation. After that, the flow field becomes asymmetric and vortices are shed one after another. The elastic plate begins to vibrate by the difference of hydrodynamic forces acting on the sides of it. The first-mode frequency is near to that obtained by Wall *et al*. By changing from linear elements to quadratic elements for solid displacement, the influence of second-mode frequency increases. Secondly, the case of the elastic plate made in incompressible hyperelastic material is treated. The solutions become small because of shear locking by using linear elements for solid displacement. However it is possible to avoid locking by using quadratic elements. The total volume of solid domain is also preserved as shown in the time history of the volume.

In chapter 5, the conclusions of this thesis and the future works are described.