Finite Element Analysis of Finite Deformation Problems for Bio-Polymer Materials

Bo-Sen Chuang[1], Pin-Jun Chen[2], Chien-Kai Wang[3]*

[1,2,3]Department of Civil Engineering, Tamkang University, Taiwan

*Presenter: ckwang@mail.tku.edu.tw

For shape maintenance and migration of living organisms, bio-polymer materials play important roles for the redistribution of internal forces in the biological structures. A substantial amount of observations have been made over the past decades to show how the structures composed of bio-polymers deform and identify what the characteristics of the network materials are. For example, it has been revealed both experimentally and computationally that as macroscopic loading goes, the bio-polymer materials of the network type experience alterations from entropy-directed shape changes to structural deformations, such as filament bending and stretching. In addition, the transition point happens as the levels of macroscopic stress reach around 1% of the bulk modulus of the materials. Hence, here finite element formulations are developed to solve the large deformation problems for the bio-polymer materials in solutions by introducing fluid-solid interaction forces across the immersed boundaries of the materials. The formulations of mechanics which embrace conservation equations, kinematics descriptions and computing algorithms especially developed for elaborating fluid-solid interaction modeling are also the main theme of this research.

The concept of the fluid-solid finite element formulations in this research is an adaptation of Peskin's IB method. In this study, we are further proposing that fluid-solid interaction forces acting on the neighboring fluid and solid particles are naturally action and reaction to each other satisfying Newton's third law. For boundary value problems in solid mechanics, we consider a hyperelastic material model with the Neo-Hookean material description including nonlinear material behaviors and large shape changes for an isotropic solid to understand mechanical responses of biological soft materials under environmental loading related to possible physiological states. For model problems of viscous incompressible fluid in fluid dynamics, the Navier-Stoke equations of the incompressible Newtonian fluids are utilized by introducing the finite difference operators and subjecting proper initial and boundary conditions. Upon the proposed algorithm above, a numerical experiment is designed to solve the oscillation in transverse direction of the cross section of the initially deformed collagen fibril in solutions with different NaCl concentrations. The computational results clearly illustrate that the collagen material becomes laxer along the transverse directions of its cross section while staying in the solutions with lower concentrations of sodium chloride. Finally, we anticipate that this technique will open doors for understanding more physiological states of biological specimens under environmental loading.

Keywords: Finite element method, fluid-solid interaction, soft materials, nonlinear elasticity.