A new multiscale computation method for geometrically nonlinear analysis of 3D fluid actuated cellular structures

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Abstract

Plants exhibit a variety of reversible motions, such as the slow opening of pine cones and the impulsive closing of Venus flytrap leaves. With this inspiration, a concept of fluid actuated cellular structures has attracted a growing interest in recent years. These smart materials have a wide array of applications, from morphing aircraft wings to soft robotics. In this paper, we present an efficient multiscale computational formulation of the geometric nonlinear analysis of three dimensional (3D) fluidic actuated cellular structures. In this formulation, the relations between the microscopic properties of motor cells and macroscopic behaviors of the fluidic cellular structures are established by the numerically constructed multiscale displacement and fluid pressure base functions. The microstructure and complex actuation behaviors can be equivalent to a simple macroscopic coarse element through those constructed multiscale base functions. Then the equivalent tangent stiffness matrix and internal force vector of the macroscopic coarse element are deduced based on the co-rotational approach, which can describe the motion of macroscopic coarse element clearly and efficiently. Thus the original geometric nonlinear problem of the 3D fluidic cellular could be solved iteratively on the macroscopic scale, which will greatly save computing time and cost. After all the macroscopic calculations, the microscopic mechanical and actuation responses could be retrieved and calculated from the macroscopic solutions by using multiscale shape functions. To verify the validation and efficiency of the proposed multiscale computation formulation, several typical numerical examples are carried out. The results indicate that the developed multiscale formulation not only could provide high precision solutions but also has high efficiency for the numerical analysis of the 3D fluid actuated cellular structures.

Keywords: Fluid Actuated Cellular Structures, Smart materials, Geometrically Nonlinear Analysis, Multiscale finite element method, Co-rotational formulation