New formula of geometrically exact shell element undergoing large deformation and finite rotation

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Abstract. The paper develops two new geometrically exact shell elements that allow large deformation and finite rotation. Both of them are based on the Reissner-Mindlin shell theory, where the shell is considered as a surface with oriented directors. Accordingly, two different descriptions for rotational fields of oriented directors are given. The first description takes advantage of two rotational variables of the pseudo-rotation vector, and the second one employs two spherical coordinates to avoid the vectorial parameterizations of rotation tensor. With the application of Mixed Interpolation of Tensorial Components (MITC), these shells are shear-locking free, feature second-order accuracy and contain nine nodes. Each node has five degrees of freedom, three for translations and two for rotations. Finally, numerical simulations show these new shell elements have the ability of dealing with large deformations and finite rotations with high efficiency and good accuracy.

Introduction

The computational shell theory was studied over the past decades, and various shell elements have been developed for the linear and nonlinear analysis. Up till now, many researchers are still devoted to modeling the nonlinearities in computational shell theory, such as large deformations, buckling and post-buckling etc. When measuring shear strains through the thickness, the Reissner-Mindlin shell elements [1] are necessary. This type of elements uses rotational degrees of freedom to describe the rotations of the fiber, resulting in shell elements with five or six degrees of freedom per node. It has been pointed out [2] that these rotational degrees of freedom are frequently the source of convergence difficulties in implicit structural analyses. This paper presents two different approaches to describe the arbitrary rotations of the fiber by using the pseudo-rotation vector and the spherical coordinates of the fiber, respectively. Unlike the classical approach that treats the rotations of fiber as general rotations of rigid body in space, this paper points out for the first time that finite rotation of the fiber is completely different from finite rotation of the rigid body described by using the rotation tensor. The fiber can be mathematically viewed as a unit vector containing two independent parameters, such that its rotation can be described by the pseudo-rotation vectors with two components in an incremental analysis, then determines the orientation of local Cartesian basis. It affords powerful theoretical background for the formula of fiber displacement in Hughes doubly curved shells[3]. The second description utilizes the spherical coordinates of fiber with unit length. Its orientation can be determined by the rest two of spherical coordinates.

Results and Discussion

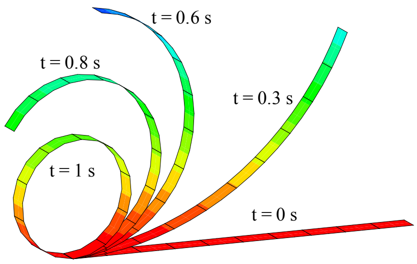

Figure 1: Deformed configurations for a cantilever beam under pure moment.

Figure 1 shows the ability of the new shell elements to predict large deformation. A cantilevered beam meshed into 10 shell elements is deformed into a pure circle when the torque applied to the end of the beam increase form zero to the critical value. In summary, the innovations of this paper include: 1) Two new geometrically exact shell elements with simplified formula are developed to model the relatively thin structures with large deformations and arbitrary motions, efficiently. 2) The Green-Lagrange strain tensor is modified to include only the approximations of higher-order terms, ensuring that the shell element can efficiently describe the geometrical nonlinearities. 3) It points out for the first time that finite rotation of the fiber is completely different from finite rotation of the rigid body described by using the rotation tensor.

References

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