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GEOMETRICALLY NONLINEAR FE MODELING FOR PIEZOELECTRIC INTEGRATED PLATES AND SHELLS

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1 Introduction

Plates and shells with integrated smart materials, e.g. piezoelectric, magnetostrictive, etc., are usually called smart structures in the literature. These structures easily perform at large deflections and rotations, which means geometrically linear shell theories are not applicable for modeling of thin-walled smart structures.

A large number of papers can be found in the literature, which developed geometrically nonlinear FE models using von Kármán type nonlinear shell theory, moderate rotation shell theory, and fully geometrically nonlinear shell theory. Nevertheless, those nonlinear shell theories are only valid for the structures undergoing moderate rotations. In order to deal with smart structures undergoing large deflections and rotations, an advanced nonlinear FE model has to be constructed, such that the static or dynamic behavior can be precisely predicted. The shell theories, which includes fully geometrically nonlinear strain-displacement relations and considers unlimited finite rotations, are called large or finite rotation theory. This large rotation shell theory is equivalent to three-dimensional FE method considering full geometric nonlinearities. As can be found that very few papers developed FE models based on large rotation shell theory, see [1, 2] among others.

2 FE nonlinear analysis

The large rotation shell theory used for static and dynamic analysis of smart structures in this paper is extended from the work of Kreja and Schmidt [3], who developed for static simulation of composite laminated thin-walled structures. The geometrically nonlinear shell theories employed in the following simulations include von Kármán type nonlinear theory (RVK5), moderate rotation theory (MRT5), fully geometrically nonlinear theory

(LRT5) and large rotation shell theory (LRT56), which are based on first-order shear deformation hypothesis, for more detailed formulations we refer to [3, 2].

The example for numerical demonstration is a PZT laminated semicircular cylindrical shell, as shown in Fig. 1, which was first proposed and calculated by Tzou and Ye [4]. The composition and the material properties of the smart shell can be found in [4, 2]. A concentrated force is applied at the tip point along the hoop direction from the bottom to the top. The static and dynamic behavior of the hoop deflection is presented in Fig. 2 and Fig. 3, respectively.

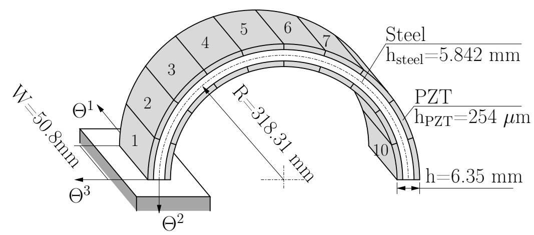

Figure 1: PZT laminated semicircular cylindrical shell

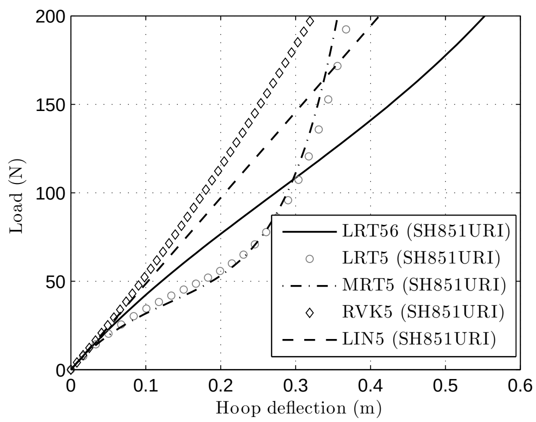

Figure 2: Static response of the hoop deflection under a concentrated force in hoop direction

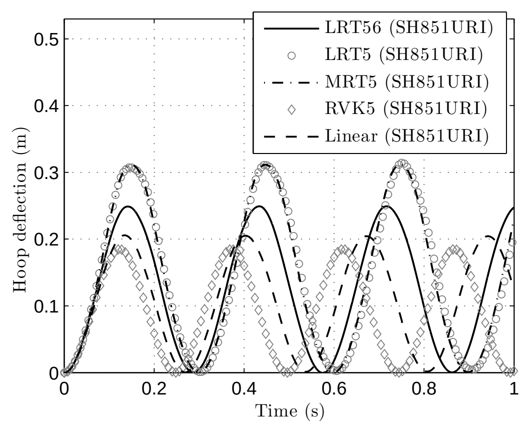

Figure 3: Dynamic response of the hoop deflection under a step tip force of 50 N

The static results show that RVK5 theory predicts stiffer displacements than linear theory does, while MRT5, LRT5 and LRT56 give softer response. It can also be observed that MRT5 and LRT5 theories predict very similar static response of the hoop displacement, which confirms that the LRT5 theory is restricted to the range of moderate rotations even though full geometrically nonlinear strain-displacement relations are considered. The hoop deflections obtained by MRT5, LRT5 and LRT56 show first a softening tendency which turns at large loads to a stiffening behavior. The figure also illustrates that big differences are existing among the results obtained by linear and various nonlinear shell theories. It can be concluded that the results obtained by LRT56 are the most accurate ones, since the full geometric nonlinearities and large rotations are considered in the theory.

The dynamic response of the hoop deflection is calculated using Newmark method with a time step 1×10^3 s for the linear case and 1×10^4 s for the nonlinear case. Since MRT5 and LRT5 theories predict similar static response, it can be seen that there is not much difference between the transient behavior obtained by MRT5 and LRT5 theories. The trend of the amplitudes and frequencies of the transient response follows the static behavior, which shows that the stiffest response is predicted by RVK5, followed, in this sequence, by the linear theory, LRT56 and MRT5.

3 Conclusion

This paper developed geometrically nonlinear FE models for piezoelectric bonded smart structures using various nonlinear shell theories, which includes von Kármán type nonlinear shell theory, moderate rotation shell theory, fully geometrically nonlinear shell theory and large rotation shell theory. The results indicate that the large rotation theory has to be considered for the structures undergoing large deflections and rotations, since simplified nonlinear shell theories may fail to predict precisely.

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