Efficient nonlinear modeling of highly flexible beam structures using geometrically exact beam models

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The study of highly flexible beam structures continues to be a subject of research as their behavior in bending often leads to complex nonlinear phenomena that can be difficult to model. Examples of such structures include cables, wires and ropes, where a simple, one-dimensional structure and low stiffness in bending combine to result in extreme deformation when subjected to certain loadings. A geometrically exact beam model is ideal for capturing the nonlinear behavior of flexible structures, yet more research is needed to improve the computational efficiency of existing solution strategies. We propose a novel method for the periodic solution of geometrically exact beam structures using a custom continuation algorithm instead of the usual solving schemes.

The defining feature of the geometrically exact beam model, as the name suggests, is the fact that all geometrical nonlinearities ($\sin\theta$ and $\cos\theta$) governing the rotation of the beam are kept exact without simplification [1]. The geometrically exact model is therefore capable of accurate representation even if the beam undergoes extreme displacement, as is the case with many flexible structures. A disadvantage of this model, however, is its complexity. Widely-used techniques for nonlinear dynamic simulation require a significant computational load when using the geometrically exact model, a load which will increase with the desired accuracy of the simulation. Instead, a newer technique for the dynamic simulation of nonlinear structures will be presented with several test cases shown.

The strategy first involves a finite element discretization of the beam systems based on the weak form variational formulation of the geometrically exact beam equations. In the case of the current plane stress condition, the system is reduced to 2D geometrically exact beam elements [2]. The weak form of the equations of motion are developed using simplified Green-Lagrange strains and linear Kirchhoff-Saint-Venant constitutive laws. The details of the finite element model can be found in [3]. The finite element model is then implemented into the interactive path-following solver, MANLAB. MANLAB combines the harmonic balance method (HBM) with the asymptotic numerical method (ANM) continuation technique for efficient solution of periodic systems [4, 5]. Advances in this technique and its application to various beam structures will also be presented.

References

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