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Bistable Cylindrical Space Frames

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Abstract

Bistable structures are structures that have two different stable configurations. Due to this interesting and distinguishing property, they are gaining popularity in many applications, such as consumer products, deployable structures, robotics and micro-structural systems. Whereas current bistable structures are fairly limited and previous research in this field has mainly focused on composite and metallic structures, this dissertation expands the range of bistable structures to a new structural form, space frames.

Double-layer cylindrical space frames, whose top and bottom layers are coaxial and have the same architecture, are the main object of this research. We will explore whether this kind of space frames can be made bistable; under what conditions they are bistable; what are the geometric relationships between their two stable configurations and how the bistability changes with changes of the structural properties of the space frames. The investigation will start with an analytical approach to preliminarily assess the bistability of several space frames, which is followed by detailed finite element analysis and finally a demonstration using a physical model.

In the analytical approach, the equivalent stiffness matrix is introduced to describe the static structural properties of space frames through an equivalent continuum approach. A two-parameter inextensional deformation model is selected for the deformation of a cylindrical space frame, assuming that the mid-surface of the space frame remains cylindrical at all times but the structure is allowed to twist and change curvature. Based on this analysis, an analytical framework is developed to obtain the strain energy of a space frame under any inextensional deformation and so the bistability of space frames can be checked by looking for the existence of local minima in their strain energy contour plots. Space frames based on a lattice of squares, right-angle triangles, isosceles triangles and a particular type of negative Poisson's ratio structure are all found to be bistable under certain conditions. The relationships between their curvatures in the two stable configurations are also presented.

A computational analysis of space frames based on these four lattices is then carried out to further investigate this bistable property. Finite element models are set up in ABAQUS and a nonlinear geometrical analysis is carried out to confirm the bistability

of these space frames. The elements of these space frames are simulated as both pin-jointed truss elements and rigid-jointed beam elements and the computational results are compared with corresponding analytical results. We discuss in detail how changes of the structural parameters will change the bistability of the space frames and how to make the simulation converge more easily.

Rapid-prototyping techniques to fabricate complex structures are reviewed and the Selective Laser Sintering technique is selected to build a physical model that demonstrates the accuracy of our analyses. A double-layer cylindrical space frame based on a lattice of squares has been built with Nylon 12 using the SLS method. On this model, experiments have been carried out to change the configuration of the model and test its bistability. We have found that the physical model is indeed bistable, and measurements of the curvature of the second stable configuration of the model show good agreement with the computational analysis where the elements of the space frame are simulated by beam elements.