
Vibration Analysis of Curved Lattice Metamaterial Structures by Using Higher-Order Shear Deformation and Modified Strain Gradient Theories

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Abstract

This study investigates vibrational behavior of curved structures based on triangular lattice metamaterials. Curved beam and shell structures couple the bending and extension states, making their behavior more complex compared to straight structures and requiring more advanced modeling theories. To address this, higher-order theory is utilized, along with modified strain gradient theory, to account for size effects in lattice structures. Strain gradient theory enables modeling structures as equivalent homogenized models with effective material properties. Governing motion equations are formulated using Hamilton's principle, and numerical solution is implemented via the differential quadrature method (DQM) under clamped boundary conditions. Numerical experiments for lattice metamaterial structures conducted with elements of commercial finite element software Abaqus demonstrate a good agreement with effective beam and shell models and detailed finite element modeling, validating the reliability of the results. This paper examines the effects of various parameters, such as the central opening angle of shells and beams, thickness of structure and lattice cells, strain gradient length-scale parameters on the natural frequencies. The findings highlight the significant influence of length-scale parameters on structural behavior. The strain gradient model shows excellent agreement with numerical simulations, particularly for thin structures. In other words, the inclusion of strain gradient effects plays a crucial role in enhancing the accuracy of analytical models. One key result reveals that, for a constant thickness, by reducing lattice cells' scale and increasing the number of cells, the structure's stiffness decreases. These results provide valuable insights for structural engineering applications, for the development of efficient, lightweight, and high-performance lattice-based curved beam and shell structure.

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