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Vibration analysis of truncated spherical shells under various edge constraints

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ABSTRACT

By means of combining Flügge's thin shell theory and energy method, a generalized approach to investigate vibration characteristic of truncated spherical shell subjected to various edge constraints is proposed. The truncated spherical shell is devided into different sections along the meridian line, in which the displacement function of truncated spherical shell along meridian and circumferential line are respectively represented by Jacobi polynomials and Fourier series. Various edge constraints can be simulated on the basis of virtual spring stiffness method in the current research. Finally, the solutions can be derived by meand of Ritz method. The dependability and exactness of current method have been proved by the comparison between current method, FEM and related literatures. The dimensionless frequency parameters of different truncated spherical shell under various edge constraints are displayed. In addition, the influence of geometric dimensions and boundary constraints on frequency parameters are also discussed.

1. Introduction

The spherical shells with cutout have been used extensively in different engineering branches for its geometry shape and mechanical property. For example nuclear power plants, aviation and marine engineering [1–4]. The truncated spherical shells usually bear excessive excitations and extreme loads in these circumstances, which may lead to excessive vibration. Accordingly, it's necessary and meaningful to analyse vibration behavior of truncated spherical shells to avoid resonance damage, especially in the process of designing.

Many researches have been conducted with the aim of studying the vibration behavior of truncated spherical shell, such as: pseudospectral method, finite element method and Chebyshev-Galerkin spectral method. In retrospect, the literatures are listed as below: Wu and Heyliger [5] analyzed the free vibrate of truncated spherical shells by means of two-dimensional first order shear deformable shell theory. The displacement function in the merdian and circumferential directions were represented by Hermite interpolation polynomials and Fourier series respectively. The free vibration of truncated-spherical shells was also investigated by Lee [6] on the basis of pseudospectral method, where the displacement components along the axial and circumferential direction were respectively expressed as Chebyshev polynomials and Fourier series. Ram and Babu [7] studied free vibration characteristic of hollow spherical shell by means of the finite element method. A shell element with nine degrees of freedom at each node was put up. Alwar and Narasimhan [8] analyzed non-linear behavior of laminated orthotropic truncated spherical shells on the basis of the principle of virtual work. Vu et al. [9] studied vibration of truncated spherical shells which is made of functionally graded materials (FGM).

In addition, many researchers also conducted researches about the free vibration of typical revolved structures such as spherical shells, cylindrical and conical shells: Narasimhan and Alwar [10] presented a Chebyshev-Galerkin spectral method to investigate the vibration characteristic of laminated orthotropic spherical shells. In addition, the effects of geometry parameters and material parameters on frequencies and mode shapes were also discussed. Du et al. [11] suggested a unified formulation for dynamic behavior analysis of spherical cap with uniform and stepped thickness distribution under different edge constraints. The comparison between FEM, modal test and published literatures proved the veracity and effectiveness of methods presented in the research. Singh and Mirza [12,13] investigated the vibration characteristics of spherical shells subjected to different edge restraints by means of FEM. Natural frequencies of spherical shells with different geometry parameters have been analyzed. Then the author presented displacement fields of each segment by quintic Bezier functions, which was proved efficient and accurate using only two to four shell segments of spherical shells. Qu

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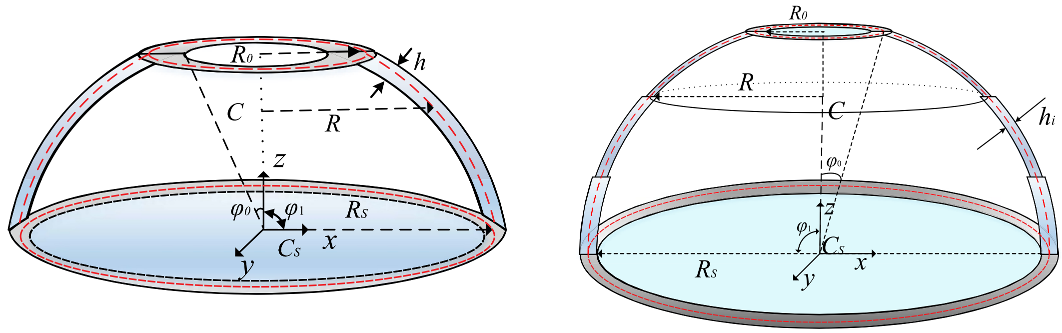
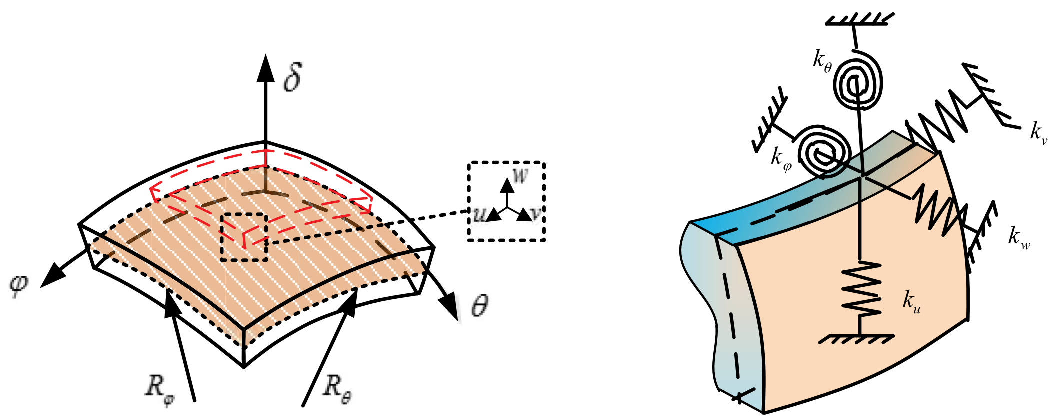


(a) Uniform truncated spherical shell. (b) Stepped truncated spherical shell.

Fig. 1. Geometric Symbols and coordinates of truncated spherical shell. (a) Uniform truncated spherical shell. (b) Stepped truncated spherical shell.



(a) Derivation block (b)Edge springs of derivation block.

Fig. 2. Derivation block and edge spring of block. (a) Derivation block. (b)Edge springs of derivation block.

et al. [14,15] put up a domain decomposition approach to study vibration behavior of revolution shells including spherical, cylindrical and conical shells. Jin et al. [16,17] investigated vibration characteristic of conical and cylindrical shells by means of an accurate modified Fourier series solution. By means of combining Fourier series and Rayleigh–Ritz method, the solutions can be obtained accurately and fast. Khoa et al. [18] studied vibration characteristic of cylindrical shells by means of Reddy's third-order shear deformation shell theory. Wang et al. [19] studied vibration characteristic of doubly-curved shells of revolution by the combination of energy method and Improved Fourier series method. Chan et al. [20] investigated the vibration behavior of truncated conical shells on the basis of FSDT and Galerkin method. Zappino et al. [21,22] dealt with free vibration of reinforced thin-walled cylinders and plates by means of finite element method (FEM). The reinforced structures are built by components such as skin, ribs, and stringers. In addition, Carrera unified formulation (CUF) is also used.

To solve the non-uniform distribution of forces on structures in practical engineering, structures with stepped thickness also exist extensively. Some investigations have also been conducted: Lee [23] introduced a Chebyshev-tau method to investigate vibration characteristic of stepped beams. The comparison between proposed method of author with related literature and experimental measurements proved the accuracy and reliability. Xiang and Wang [24] studied vibration frequencies of rectangular plates with stepped thickness by means of an analytical method on the basis of Levy method and the state-space technique. Qu et al. [25,26] proposed a unified method namely domain decomposition method to investigate vibration characteristic of stepped cylindrical and conical shells. Duan et al. [27] presented an extensive discrete singular convolution (DSC) method to analyse free vibration of uniform and stepped circular thin plates.

It's easy to find that most researches of vibration of stepped structures are about beams, plates and cylindrical shells. Few researches about truncated spherical shell with stepped thickness have been conducted. In addition, most researches mentioned above are restricted to classical boundary conditions. However, elastic boundary conditions also appear widely in reality. Therefore, a generalized manner to solve vibration characteristic of truncated spherical shells with uniform and stepped thickness subjected to classical and elastic edge constraints is necessary and meaningful. In the current research, the unified analytical model of uniform and stepped truncated spherical shell is established by the combination of Flügge's thin shell theory and multi-section division method. Complex boundary edge constraints of truncated spherical shells can be easily achieved by setting proper stiffness values to virtual spring. The veracity and dependability of current method are also proved by the comparison between current method, related literatures and FEM.