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Free vibrations of fluid-filled cylindrical shells on elastic foundations

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Abstract

The free vibration characteristics of fluid-filled cylindrical shells on elastic foundations are presented by a semi-analytical finite element method. A shell is discretized into cylindrical finite elements where shell governing equations based shape functions in the longitudinal direction are used instead of the usual simple polynomials. Non-uniformities of the foundations in the circumferential and longitudinal directions are handled by the Fourier series and an element mesh strategy, respectively. The fluid domain is described by the potential flow theory. The hydrodynamic pressure acting on shells is derived from the condition for dynamic coupling of the fluid-structure. The effect of fluid in a shell, shell geometries, and foundation parameters on the dynamic behavior of fluid-containing shells is investigated. Numerical results based on the present method converge more rapidly than those obtained by the simple polynomial formulation. The method is suitable for the problem considered due to its generality, simplicity, and potential for further development.

Keywords: Free vibration; Cylindrical shell; Elastic foundation; Fluid-filled; Finite element method

1. Introduction

Cylindrical shells are widely used in engineering fields because of their strength characteristics. They are used in the form of tanks, water ducts, process equipment,

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subsea/ground pipelines, and in many other applications. Therefore, the dynamic behavior of cylindrical shells containing fluid is of substantial practical interest and it has been widely investigated [1–8]. The present paper deals with the free vibration of completely fluid-filled cylindrical shells on elastic foundations.

Lakis et al. [8,9] have developed the hybrid finite element formulation for cylindrical shells based on analytical shape functions which are derived from the shell governing equations. The analysis of whole buried pipelines subjected to sinusoidal seismic waves, differential settlement, and dislocation of the ground has been studied by Yang et al. [10] using shell finite elements. Palliwal et al. [11,12] have investigated the free vibrations of whole buried cylindrical shells in Winkler and Pasternak foundations by using the direct solution to the governing equations of motion. In the paper, the elastic bed is distributed uniformly over the whole circumference. However, cylindrical shells are generally laid on or placed in the elastic foundation, so that the foundation only covers a part of the shell in the circumferential direction, leading to a more complex problem. Free vibrations of cylindrical shells simply supported at both ends with a non-uniform elastic foundation in the circumferential direction have been investigated by Amabili and Dalpiaz [13] based on the Rayleigh–Ritz method. The elastic foundation was assumed to be uniformly distributed over the whole cylinder length in the longitudinal direction. Later on, complicating effects due to the contained inviscid fluid, elastic bed of partial axial and angular dimensions, intermediate constraint and added mass are considered by Amabili and Garziera [14]. In the investigation, the linear modes of simply supported shells vibrating in vacuo are used as admissible functions, and the solution is obtained with the artificial spring method. Static and free vibration analysis of cylindrical shells partially buried in elastic foundations based on the semi-analytical finite element method has been studied by Gunawan et al. [15]. This analysis used the usual simple polynomials as shape functions in the longitudinal direction.

In this paper, the dynamic behavior of fluid-filled cylindrical shells on elastic foundations undergoing the linear vibration is studied by using the Hybrid FEM developed by Lakis et al. [8,9]. The shell is discretized into cylindrical finite elements and the foundation is modeled by elastic springs and may be distributed in the circumferential and longitudinal directions by using the Fourier series and an element mesh strategy, respectively. A linear potential flow theory is used and the fluid domain in the sectional plane is treated analytically without discretization into finite elements. The effect of fluid in the shell, shell geometries, and foundation parameters on the natural frequency of the vibrating system is presented. In addition, numerical examples corresponding to shells partially suspended on elastic foundations and to shells on non-uniform elastic foundations in the longitudinal direction are also given.

2. Analytical model and formulation

The structure is an isotropic thin elastic cylindrical shell with Young's modulus E, Poisson's ratio υ, radius of the middle surface R, thickness h, and length L. The foundation is represented by continuous elastic (axial, circumferential, radial, and rotational) springs and distributed on a limited arc. The axial, circumferential, radial, and rotational spring