Olena Sierikova
Editor

The Fundamentals of Boundary Element Methods

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Contents

Chapter 1

Boundary Element Methods for Liquid Hydrocarbon Reservoirs' Vibration Analysis

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Abstract

Flammable and combustible liquids accumulation on a relatively small area of the tank park leads to an increased environmental and fire hazard of such productions. The possible dangerous liquid leakage and depressurization of tanks negatively affects the surrounding area environment state. A fire in a tank is one of the most dangerous emergency situations that could lead not only to significant material and environmental damage, but also to human casualties. The situation is also complicated by the economically determined tendency to use larger tanks, which significantly increases the flammable liquids volume per unit area. This, in turn, increases the fire spreading risk to neighboring tanks in the absence of timely localization and elimination of the fire. It is urgent and necessary to improve the researching methods of the materials properties of liquid hydrocarbon tanks and to assess the external factors effects of natural and technogenic origin on these environmentally dangerous objects. The determining method of the dynamic characteristics of shell structures made of steel and partially filled with liquid (petroleum products) has been developed in the paper. The dynamic characteristics numerical analysis for the model of liquid hydrocarbons storage tanks has been carried out. The shell structures optimal parameters to reduce their deformations during fluid oscillations (using the liquid hydrocarbon example) have been determined. It has

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been proved that taking into account the tank walls elasticity leads to the significant decrease in the oscillation frequencies compared to the unfilled shells frequencies, while the lowest frequencies of filled and unfilled shell structures could correspond to different wave numbers. Extending the tanks service life, preserving their tightness and stability under various natural and technogenic influences, preventing leaks, spills and fire hazards is necessary to increase the environmental safety level of the surrounding areas.

Keywords: boundary element methods, liquid hydrocarbon reservoirs, vibration analysis, environmental safety

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Chapter 2

Boundary and Finite Element Methods in Nanocomposites Effective Elastic Characteristics Estimation

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Abstract

The main objective of this research has been to develop competent methods to estimate effective elastic modulus of composites and nanocomposites with randomly arranged cylindrical nanoinclusions with different ratios of fiber length to its thickness. The concept of representative volume elements has been involved. Series of calculations has been carried out for the nanocomposite material consisting of metallic aluminium matrix with inclusions as the carbon nanocylinders.

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As a result of these calculations, elastic properties for the orthotropic composite material have been obtained, namely, Young's modulus, shear modulus, Poisson's ratio. It has been demonstrated that distributions with uniaxial filler orientation in the matrix, the inclusion shapes and properties, have a significant effect on the final elastic, orthotropic composite properties. The proposed models and methods provide an effective tool for predicting the mechanical properties of three-dimensional matrix nanocomposites.

Keywords: randomly arranged cylindrical inclusion, nanocomposites, representative volume element, boundary element methods, finite element methods, environmental safety

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Chapter 3

Boundary Element Methods in One-Dimensional Singular Integral Equations

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Abstract

The aim of this paper is to analyze numerical estimations effectiveness in one-dimensional singular integral equations implementing boundary element methods. The types of elements have been investigated. Especially attention has been paid out to choose collocation points. The constant, linear, quadratic, and cubic approximations of densities along the boundary elements have been considered, and the effectiveness of these approximations has been estimated. The optimal positions of the collocation points have been obtained for accurate calculations of the singular integrals. The obtained numerical results show that even with a small number of linear elements, they give good accuracy, but it couldn't be improved for $n<100$. The convergence rate with quadratic elements changes according to a quadratic law; cubic elements are according to a cubic one. To obtain stable numerical schemes using boundary element methods, it is necessary to arrange control points in a special way, namely in maximum value points of responses.

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Keywords: one-dimensional boundary elements, collocation points, density approximations

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Chapter 4

Boundary Element Methods for Hypersingular Integral Equations Over Circular Domains

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Abstract

The purpose of this study is to analyze and systematize existing and obtain new analytical solutions of hypersingular integral equations, clarify the properties of these solutions, and compare analytical and numerical solutions. Circular domains have been chosen as areas of integration. Analytical solutions of these equations have been constructed, and it has been established that the potential densities of the double layer potential repeat the character of the right parts of the corresponding hypersingular equations. The boundary element methods have been applied to numerical simulations. The comparison of numerical and analytical results has been provided. The problems of determining the stress intensity factors in an infinite elastic body have been analyzed using different approaches concerned with hypersingular integral equations as well as with finite element methods. The solutions of hypersingular integral equations in vibration analysis of circle plates have been presented.

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Keywords: Laplace's equation, boundary value problems, fluid-structure interaction, hypersingular integral equation, analytical and numerical solutions, stress concentration

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Chapter 5

Boundary Element Method Testing for Axially-Symmetrical Problems

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Abstract

The purpose of this study is to develop and test boundary element methods for axially-symmetrical integration domains. The liquid-filled revolution shells' vibrations have been considered in coupled formulation. The shell motion equation in the absence of external perturbations has been described on the basis of the Ostrogradsky–Hamilton principle. To determine the fluid pressure on the wetted surface the potential theory has been involved. It could be possible to reduce the problem under consideration to singular integral equations. The considered integration area specific has been taken into account. The expressions for kernels have been obtained and analysed. For testing the proposed method some analytical solutions have been applied. The convergence and effectiveness of the axially-symmetrical boundary element method have been demonstrated.

Keywords: elastic shell of revolution, boundary element method, fluid-structure interaction, analytical and numerical solutions

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Chapter 6

Construction of Fundamental Solution of {1,2}-Approximation Static Equations of Momentless Stress State for Transversely-Isotropic Plates

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Abstract

The problem of static transversely isotropic plates, which are under the action of a force was considered. Used static equations of {1,2}-approximation obtained by decomposition of the desired functions in Fourier series in Legendre polynomials with respect to the thickness of the coordinates. These equations take into account all the components of the stress tensor, including the transverse shear and normal stresses. Numerical studies demonstrating the effect of elastic constants on the components of the stress-strain state of a transversely isotropic plate.

Keywords: {1,2}-approximation, fundamental solution, transversely-isotropic plates, static equations, momentless stress state, integral representation, boundary element method

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Chapter 7

Boundary Element Method in Hydroelastic Interaction Problems of Structural Elements

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Abstract

Modern equipment usually operates under increased power and temperature loads. This requires determining the strength and dynamic characteristics of structural elements at the design stage in order to substantiate the reliability of operation. Experimental studies make it possible to estimate such characteristics with sufficient accuracy. However, conducting natural experiments is an expensive and not always safe procedure. Therefore, studies of the strength and vibrations characteristics of structural elements based on computer modelling are relevant. Nevertheless, the external load parameters cannot always be determined unambiguously. In this work, an effective method of analysing hydroelastic vibrations of structural elements has been developed, based on the application of potential theory methods, and elements of fuzzy logic. First, the problem of forced hydroelastic oscillations of a structural element has been solved in a deterministic formulation. It has been assumed that the fluid is ideal and incompressible, and its motion, induced by small oscillations of the elastic element, is vortex-free. Then there exists a velocity potential that satisfies the Laplace equation. The method of given modes has been

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applied, the oscillation modes of the structural element without taking into account the attached fluid masses have been chosen as the basic functions. To find the pressure of the liquid on the structural element, a hypersingular integral equation has been obtained, the solution of which has been carried out by the boundary element method, using the unknown density approximation by constant values on the boundary elements. Next, the load parameters have been fuzzified using triangular membership functions. Then the randomness of load parameters has been added to the mathematical model. Fuzzy stochastic differential equations have been obtained, which have been solved by a numerical method. The presented numerical results demonstrate the influence of the uncertainty of the initial data on the behaviour of structural elements.

Keywords: hydroelastic oscillations, hypersingular integral equation, boundary element method, methods of fuzzy mathematics

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