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Fluid-filled Shell Structures and Their Applications in Biomechanics

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***Abstract*—Structures in the form of thin-walled shells containing liquid are extremely common in various areas of modern technology, as oil storage facilities, water towers, rocket launch tanks and manifolds for storing chemicals. Failure of such structures is fraught with a wide range of negative consequences. The problems of fluid-structure interaction of structural elements partially filled with liquids, are in the focus of many research since the 60s of last century. The growing interest in biological materials and medicine has also accentuated the importance of studying the dynamical behavior of shell-like structures with fluids. In this paper, effective numerical methods to estimate the frequencies and modes of elastic shell vibrations coupled with liquid sloshing are elaborated. The approach is relied on using the mode superposition method as well as boundary and finite element methods. The problem under consideration consists of three stages. At first, it is necessary to obtain the frequencies and modes of empty elastic shell, at second stage the sloshing modes and frequencies are received. At third stage and modes and frequencies of elastic shell vibrations coupled with liquid sloshing are obtained. Own modes and frequencies of spherical and conical steel shells are estimated, as well as modes and frequencies of eardrum interacting with liquids. The influence of impact loads on the tympanic membrane is analyzed.**

Keywords*—shell-like structures, eardrum vibrations, fluid-structure interaction, finite and boundary element methods, fundamental frequencies.

I. INTRODUCTION

The problems of fluid-structure interaction (FSI) have been the focus of many research since the middle of the last century. This interest was caused by the failures of the first missions of launch vehicles to Jupiter, and with powerful earthquakes that caused destructions of tanks for storing water, flammable substances, and oil products. Intense sloshing of the liquid in the fuel tanks can lead to losing launch vehicles stability, departing the calculated trajectories and even to the complete destruction of structures.

The spillage of hazardous aggregates from tanks and oil storage facilities leads to severe environmental consequences [1]. Earthquake hazard analysis has been carried out in [2],[3].

The phenomenon of sloshing and FSI are also important in the logistics industry, rocket science, food and chemical industries, works [4]-[8] are devoted to the study of this phenomenon.

One of the most important components of the phenomenon of liquid sloshing is its damping, the study of which is accomplished in works [9],[10], where floating covers, horizontal, vertical and conical partitions [11]-[13] are considered.

In [14],[15], the use of composite and nanocomposite materials was proposed, which help not only increase the strength of structures, but also change the frequencies of hydroelastic vibrations to avoid resonances.

One of the promising areas for studying shell structures during their interaction with liquid is biomechanics and medicine. The human body consists of many shell structures, as capillaries, blood vessels, internal organs. In [15],[16] vibrations of the eardrums, resulting from the impact of a sound impulse, are considered. It should be noted that in otitis, the tympanic membrane can be considered as a thin shell or membrane that interacts with fluid [17]. Otitis media with effusion is a common ear disease resulted from Eustachian tube dysfunction or inflammation of the middle ear caused by bacterial or viral infections [18]. Biomechanical methods relied on computer simulations become the basis for diagnosing and providing recommendations for the treatment of middle ear diseases [19]. In [20] the harmonic analysis was complited with frequencies from ultrasound to infrasound. Sound transmission from outer to inner ear was considered in [21].

But there are still a number of questions that require elaboration of numerical methods. This paper is devoted to developing advanced numerical techniques based on coupled finite and boundary element methods for estimations free and forced vibrations of shell-like structures. It also contributes in studying the behaviour of eardrum by incoming pressure waves.

II. METHODOLOGY

A. Basic equations of continuous medium movement

To describe the movement of both elastic bodies and liquids, the classical continuous medium relations are used, namely, equation of motion in stresses

$$\sigma_{ij,j} + X_i = \rho \frac{\partial^2 u_i}{\partial t^2} 0; \quad i,j = 1,2,3, \qquad (1)$$

- Cauchy's relations for small deformations

A similar shock wave when exposed to a child causes much more severe consequences, since the child's membrane is much more vulnerable to stress. Consequences may include bleeding, headache, contusion, spatial disorientation etc.

Since the parameters of the human eardrum have not been sufficiently studied and lie within wide limits, in the future it is proposed to use the concepts of fuzzy mathematics to homogenize data.

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