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Dynamic Verification of a Grid Structure Numerical Model Consisting of Different Stiffness Parts

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Abstract

The work presents the results of experimental and numerical investigations into the natural frequencies of grid structure containing parts made of materials with significantly different elastic modulus. A good example of such structure is human thorax. Firstly, the elastic properties of bone and cartilage materials were obtained by using bending and compression tests. The elastic modulus of the compact substance of the bone is 8…12 GPa, coastal cartilage – 70…90 MPa. The maximum failure force and bending strength were defined under the bending impact test (using a drop tower impact system). This bone strength is ~175 MPa (1.5...2 times more of the values obtained in static bending). Then, a three-dimensional model of a human thorax was developed allowing one to predict their mode shapes and the natural frequencies using the finite element method (ANSYS software). The verification of the model was carried out by comparing the experimental (in vivo) and numerical natural frequencies of a human thorax.

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Keywords: mechanical properties; natural frequency; numerical modeling; finite element method; human thorax.

1. Introduction

Grid structures constitute a significant class of modern technology constructions (frames of a vehicle such as trams, buses, trains), which are generally used, metallic materials with similar values of the elastic moduli [1-3]. Research methods of its dynamic characteristics (mode shapes and natural frequencies) have been well studied [1, 3-6]. The living objects have large difference of mechanical properties of the materials as opposed to technical objects.

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A good example of a responsible grid construction may be human rib cage, which consists of the bone and cartilages [7, 8]. Local impact to the human thorax can lead to a bone fracture and internal injuries. Body armors are used preventing this type of injury [9-13]. There are a small number of papers where authors study the mechanical properties of biological tissues and create different level models (analytical and numerical ones) [8, 10, 14-16].

It is well known that biological tissues have a wide spread of the mechanical properties, which are also dependent on the strain rate [8, 17- 21]. The CPU time depends on the detalization level of the task. Model can give answers to a few specific questions (low-parametric model) or indefinitely large number of questions (e.g., cases of loading) – three-dimensional detailed model with parts having very different elastic and strength properties. Two big problems are in this routine: proper mechanical properties of tissues and appropriate verification procedure of models.

In this work, mechanical properties of swine bone and cartilage were defined by tests. The swine materials were investigated as a model materials because properties are analogous to the characteristics of a human tissues. The obtained experimental data were used in the three-dimensional numerical model of human thorax to determite natural frequencies (two model: without and with soft tissues). Verification procedure on real humans has the definite pain limitation. The models were verified by a comparison of the natural frequencies of human thorax with the experimental data (obtained in vivo by slight impact in sternum bone).

2. Experimental and computational parts

Experimental data of mechanical properties were used by quasi-static and dynamic tests and investigation of natural frequencies of human thorax under impact. All experiments were carried out on the equipment of research and education center "Experimental Mechanics" of South Ural State University. The data obtained were used below in the numerical three-dimensional model of the human thorax.

2.1. Experimental determination of mechanical properties of the bone

Experimental investigation of mechanical properties of bone was performed under static and dynamic bending tests (universal test machine Instron 5882 with loading rate 40 mm/min and drop tower impact system Instron CEAST 9350 – impact speed 2 m/s). Sample tested in three-point bending scheme, the distance between the hinge supports is 90 mm. Curves "force – displacement" were obtained (fig. 1). Ribs cross-section has a tear-drop shape, which replaced solid ellipse or thin-walled elliptic shapes. Table 1 shows the values of the elastic modulus, ultimate strength of the bone.

Table 1. Characteristics cross-section of rib in influence area.

Specimen	Test	Length of sample (*mm*)	Elastic modulus (*GPa*)		Ultimate strength (*MPa*)	
			Elliptic cross-section	Thin-walled elliptic cross-section	Elliptic cross-section	Thin-walled elliptic cross-section
1	Static	160	5.3	10.2	71	127
2		140	4.3	8.8	59	85
3		130	5.8	6.3	73	80
4	Dynamic	170	11.3	18.3	115	177
5		190	7.6	12.5	114	175

Mean elastic modulus of the bone is 5.1 GPa for solid elliptic cross-section, and 8.4 GPa for thin-walled elliptic cross-section by reducing bending static diagrams. Mean bending strength are 68 MPa for solid elliptic cross-section, and 97 MPa for thin-walled elliptic cross-section. Value of ultimate strength of material at dynamic test was substantially larger than quasi-static one. Mean elastic modulus of bone is ~8.0 GPa, bending strength is ~120 MPa for solid elliptic cross-section. Data of flexural modulus of the compact bone substance are lying from 3 to 20 GPa (ref. [17, 22]). It is worth noting that bone is inelastic behavior.