INŽENÝRSKÁ MECHANIKA 2005

NÁRODNÍ KONFERENCE

s mezinárodní účastí

Svratka, Česká republika, 9. - 12. května 2005

NUMERICAL MODELLING OF TRABECULAR BONE

J. Brožovský*, Pankaj*

Summary: *The paper discusses an alternative approach to a trabecular bone modelling. The proposed method is based on simple models that are created from finite elements with different properties. Element properties are distributed inside structure to obtain an anisotropic (or orthotropic) homogenized properties of the material.*

1. Introduction

The numerical modelling of a trabecular bone is usually based on the high resolution finite element models. These models are created by reconstruction of high resolution images of very small parts of the bone. Created models usually consist from millions of finite elements. This approach is very good for modelling of small samples of bone. But it makes modelling of larger parts to be very difficult. The another problem is that it is often impossible to get neccessary informations to create high resolution model.

This paper describes our research of different approach - a finite element modelling which is based on simpler models. It should allow creation of numerical models of much larger parts of bone. The discussed models are created from finite elements with different material properties. All used materials are assumed to be isotropic but the behaviour of whole structure is anisotropic due to possitions of finite elements with different properties.

It is necessary to measure the correctness of numerical models with experimental data. The most common parameters (bone volume to total volume ratio) are not sufficient for this task which is clearly visible in Table 1. Because of this we have been using a method based on tensor scale computation to measure anisotropy of the finite element models. This method is very close to the metod introduced in [1] which is used to measuring trabecular bone orientation anisotropy. It allows to compare the parameters of numerical models with the parameters of a real trabecular bone.

2. Finite Element Modelling

The real trabecular bone has a very complicated 3D structure. To respect this fact, our model is based on the 3D finite element analysis. The porous character of trabecular bone is proposed to be simulated by using 3D-elements of variable elasticity and strength. The 8-noded brick-shaped finite elements with three degrees of freedom in each node have been used. A in-house developed finite element code uFEM [2] has been used.

* Jiří Brožovský, Ing, PhD., VŠB-TU Ostrava, FAST, katedra stavební mechaniky, Ludvíka Podéště, jiri.brozovsky@vsb.cz

* Pankaj Panka, Dr.,School of Engineering and Electronics, The University of Edinburgh, pankaj@ed.ac.uk

3. Measurement of Model Properties

3.1 Bone Volume To Total Volume Ratio

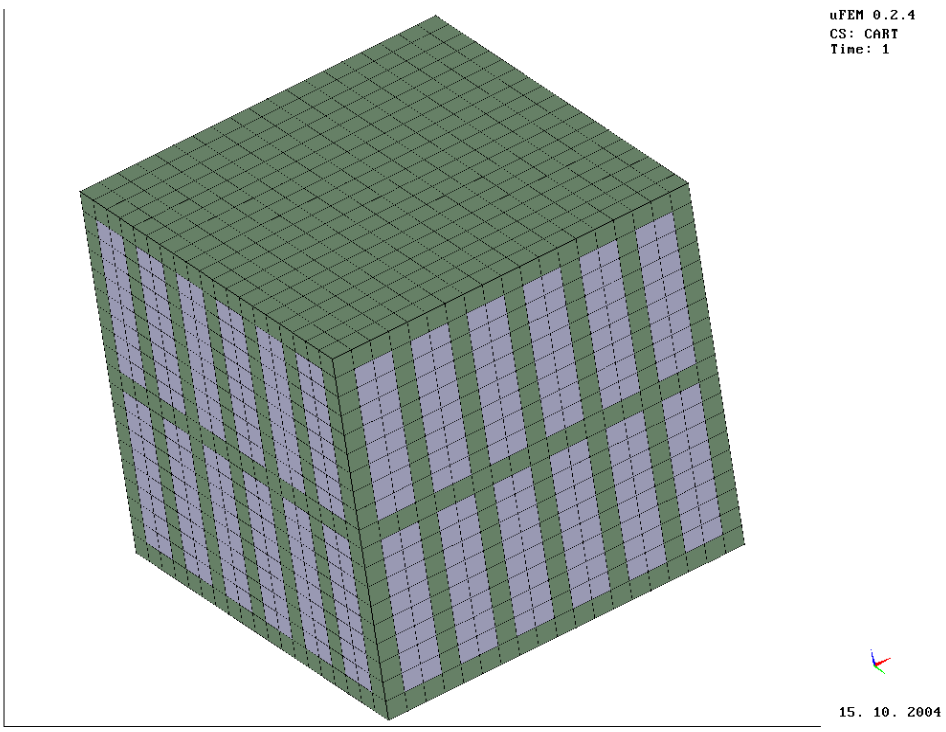
The bone volume to total volume ratio (BV/TV) is one of the traditional parameters of trabecular bone properties. It is also very easy to compute this property from a finite element model – with all elements of the same size it is a ratio of number of elements with material properties of bone to the number of all elements (the rest of elements simulates holes in a bone structures, thus these elements are not counted here).

Obviously, BV/TV ratio can't give any usefull informations about mechanical properties of bone. It is easily possible to obtain materials with the same BV/TV ratio but with very different mechanical behaviour (it is a case of the models 6 and 8 in the Tab 1, for example).

3.2 Orientation Anisotrophy Measurement Using Tensor Scale

The used approach is very close to the method described in [Saha 2004]. A tensor scale in a structure point **p** is the parametric representation of the largest ellipsoid centered in **p** which contains the same material. In 2D it is an ellipse. We will discuss the method of tensor scale computation only 2D problems only because 3D data for real bone currently are not available.

Because all the currently used numerical models consist only from two different materials, it is possible to keep the alghoritm in a very simple form [Brozovsky 2005].

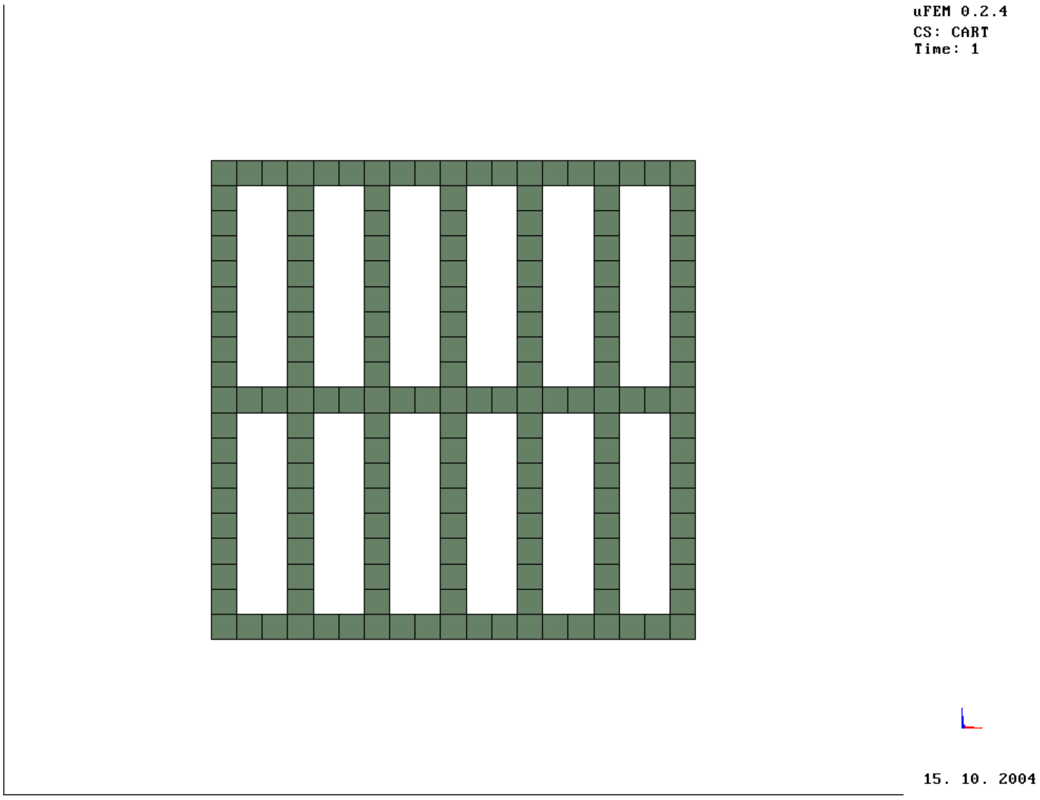


Obr. 1: Example of finite element model (both materials)

4. Computing of Mechanical Properties of Finite Element Models

To obtain a mechanical properties of our finite element models we have done two types of numerical simulations: a simple compression test and a shear test. The compression tests have been used for computation of Young modulli and Poisson ratios and the shear tests have been used for computation of shear modulli. We have been created numerical models to have a orthotropic homogenized material properties so ve have had to compute eight independent material properties (three Young modulli, three shear modulli and three Poisson ratios). All properties have been computed from the basic equations of the linear plasticity. In current phase of research we are interested in elastic material properties only.

The models have been loaded by direct displacements. We have been preferring this type of load in the tests because it allows to obtain a more correct results than force load (the uFEM currently can't work with pressures on brick elements and forces on nodes have to be carefully applied to obtain the optimal results). It also will allow us to study any part of a load-displacement curve of a non-linear solution in the future.



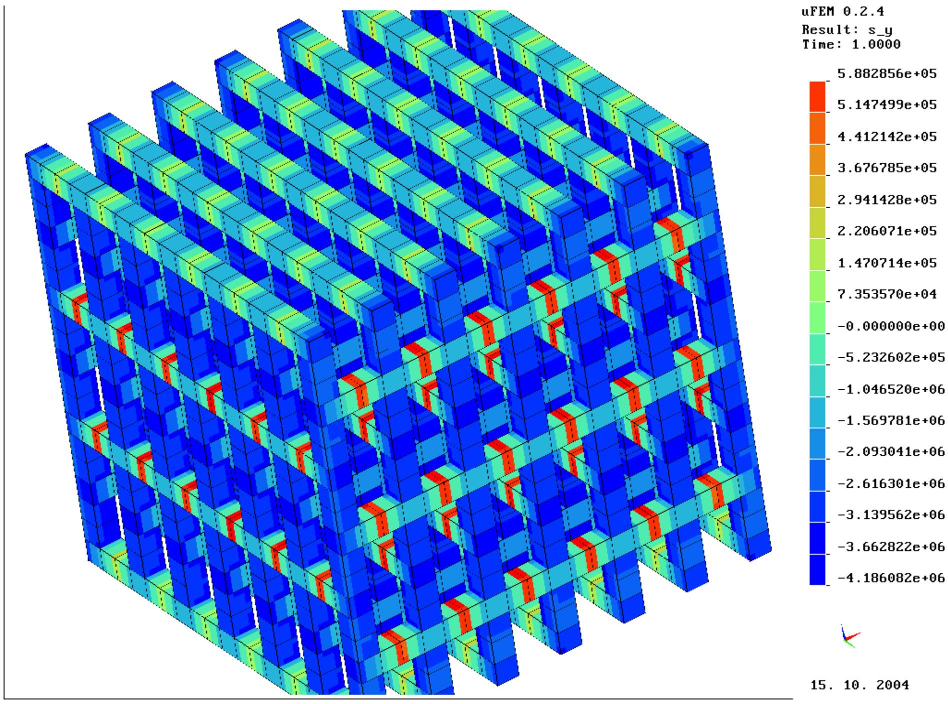
Obr. 2: Example of finite element model (tissue material only)

5. Description of Finite Element Models

All current models have been created from usual 8-node brick finite elements. The models have been cube shaped and the ortotropic behaviour has been induced by variation of material properties of individual finite elements. All models have had approximatelly 6000 of finite elements.

All material properties of finite elements have been linear and isotropic. There have been two sets of material properties – material that simulates bone tissue (E = 6 Mpa) and material that simulates empty space (E = 6 kPa). We have been created and tested several variants of distribution of material properties.

The resulting homogenized material properties are very different – the results have been showing that it is possible to create near arbitrary homogenised material properties by modifying the number and distribution of elements with tissue material properties.



Obr. 3: Stress σ_y on finite elemetn model

6. Conclusions

The discussed way of modelling of a trabecular bone can be used to make a relatively simple computational models of a trabecular bone. In current state of the research we are able to create models with arbitrary properties. Now we are working on a comparison of material indices that can be obtained from measurements of finite element model and from measurements of a real bone material. The bone volume to total volume ratio should not be a usefull material index for aur purposes because it gives no information about material anisotrophy (this fact was also verified by our results). The first results of measurements of a tensor scale parameters of a finite element models have gave better results but the final desision will be made in future.

6. Acknowledgement

The results were obtained with the support of the HPC-Europa programme, funded under the European Commission's Research Infrastructures activity of the Stucturing the European Research Area programme, contract number RII3-CT-2003-506079

7. References

Saha, P., K., Wehrli, F., W.: *A robust method for measuring trabecular bone orientation anisotrophy at in vivo resolution using tensor scale,* Pattern Recognition 37 (2004), pp. 1935-1944

Brozovsky, J.: *uFEM software homepage:* http://www.penguin.cz/~jirka/fem_en.html

Brozovsky, J., Lausova, L.: *Modelling of Trabecular Bone,* In: Proceedings of international conference Modelling in mechanics 2005, Ostrava, 2005