32nd International Conference
ENGINEERING MECHANICS 2026
Medlov, Czech Republic, May 11 – 13, 2026

MODAL ANALYSES OF THE BOVINE FEMUR USING CT, EXPERIMENTS AND FEM

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Abstract: *Modal analysis is very important in study of vibrations in biomechanics or mechanics. This article focuses on the creation of an anatomical model of a bovine cadaveric femur (i.e. CT scanning and image processing). The study itself focuses on experimental and numerical (FEM) approaches to modal analysis and a subsequent comparison of the results.*

Keywords: Modal analysis, Bovine femur, Anatomical model, Experiments, Finite Element Method

1. Introduction

Modal analysis is the popular fundamental technique in mechanics/biomechanics used to determine mainly the natural frequencies, mode (modal) shapes and damping ratios of structures and tissues. In biomechanics, it plays a critical role in understanding the vibrational behaviour of biological tissues. The bovine femur, as the typical strongest mammals' bone, is frequently studied due to its load-bearing function and susceptibility to fractures. However, in some cases, the bovine femur is widely adopted as a surrogate biomechanical model for human bone because of its comparable size, geometry, and mechanical characteristics. Understanding the modal behaviour of the bovine femur has important applications for human too. For example, in fracture prediction and prevention, implant and prosthesis design, impact biomechanics (e.g., automotive safety), bone health assessment etc. Modal analysis of such biological structures can be performed using experimental techniques, numerical simulations, or a combination of both. Each approach usually offers distinct advantages and limitations. For example, references Eiba et al. (2024), Frame et al. (2018), Gautam et al. (2021), Henyš et al. (2017), Nobakhti et al. (2017), Patel et al. (2021), Presas et al. (2021), Tarzjani et al. (2023), Yassine et al. (2018), Zanetti et al. (2009) and Zanganeh et al. (2025), Zhou et al. (2020) etc., present the state of the art.

2. Anatomical Model of a Bovine Femur

The femur was taken from an adult bull (approx. 400 kg, crossbreed of Dexter and Aberdeen Angus) with a height at the withers of 1.35 m. CT scan was performed (i.e. acquired DICOM files). Using the own

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ISSN: 1805-8256, doi: 10.21495/em2026-73

software MADIFEM, see Čepica et al. (2025), the distribution of density /kg×m^{-3}/ and Young's modulus (modulus of elasticity) /MPa/ was determined in individual finite elements based on Hounsfield units, see Valášek et al. (2011). Hence, CAD/FEM models were created, see Fig. 1. The obtained CAD/FEM model accurately describes the inhomogeneity in the distribution of density and Young's modulus in each region of the bone, see Fig. 1(d, c).

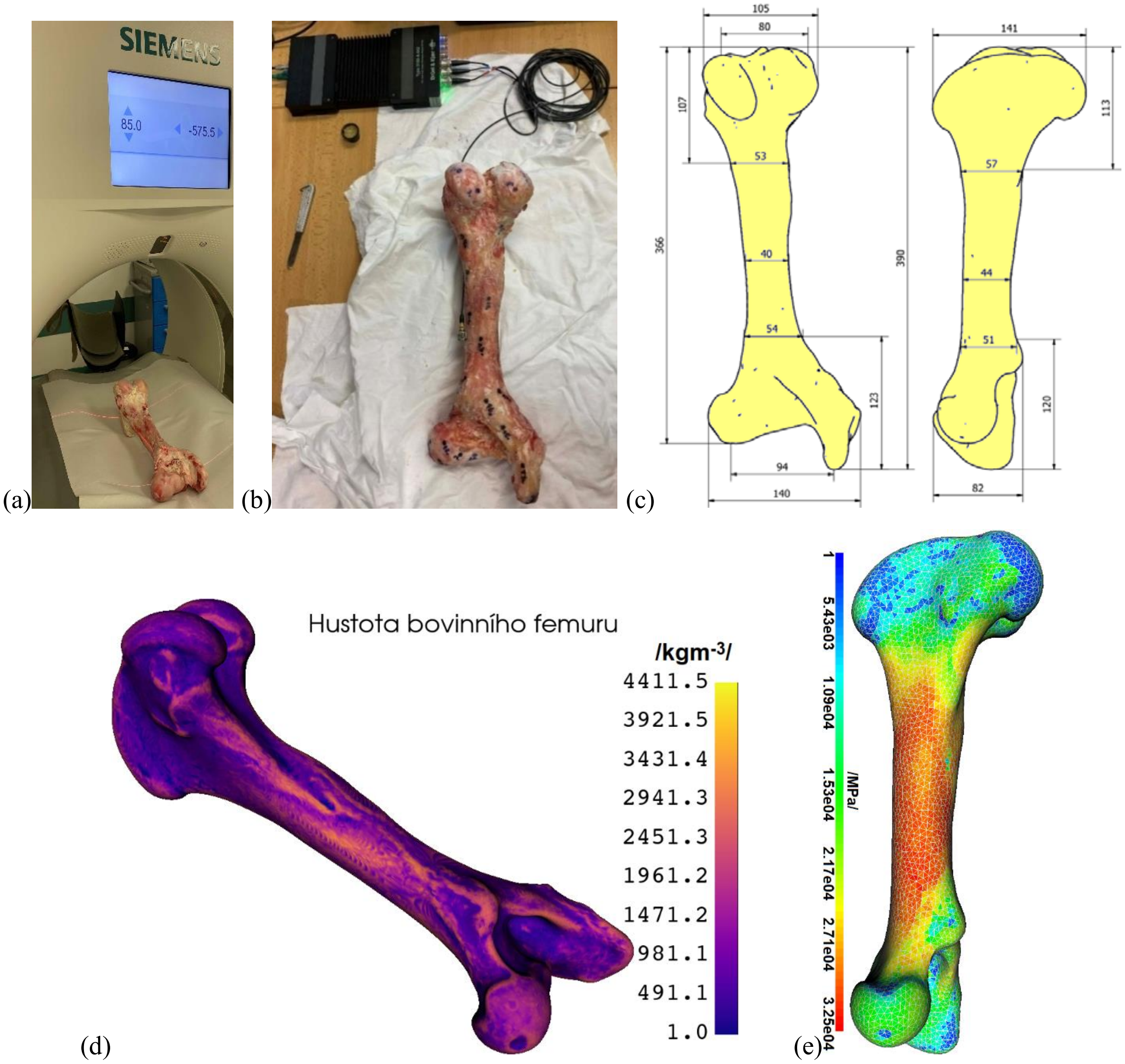

Fig. 1: Bovine femur – (a) CT - cadaver, (b) Measurement - cadaver, (c) CAD/FEM - dimensions, (d) FEM – material density distribution, (e) FEM – modulus of elasticity distribution.

3. Modal Analysis via Experiment

The bovine femur was placed on a soft foam pad. Thirty-five reference points were marked on a bovine femur to adequately cover the diaphysis, metaphyses, and epiphyses. The impact (percussive) hammer was used to hit these points and accelerometer was applied. Both the response and the excitation were recorded and evaluated by Brüel & Kjær tools, see Fig. 1(b), Tab. 1 and Fig. 2.

Tab. 1: Bovine femur – Results of experiment.

Mode	Damped frequency /Hz/	Damping /%/
1	582.57	2.00
2	641.58	5.54
3	662.75	2.03
4	731.30	2.21

5	1464.81	1.03

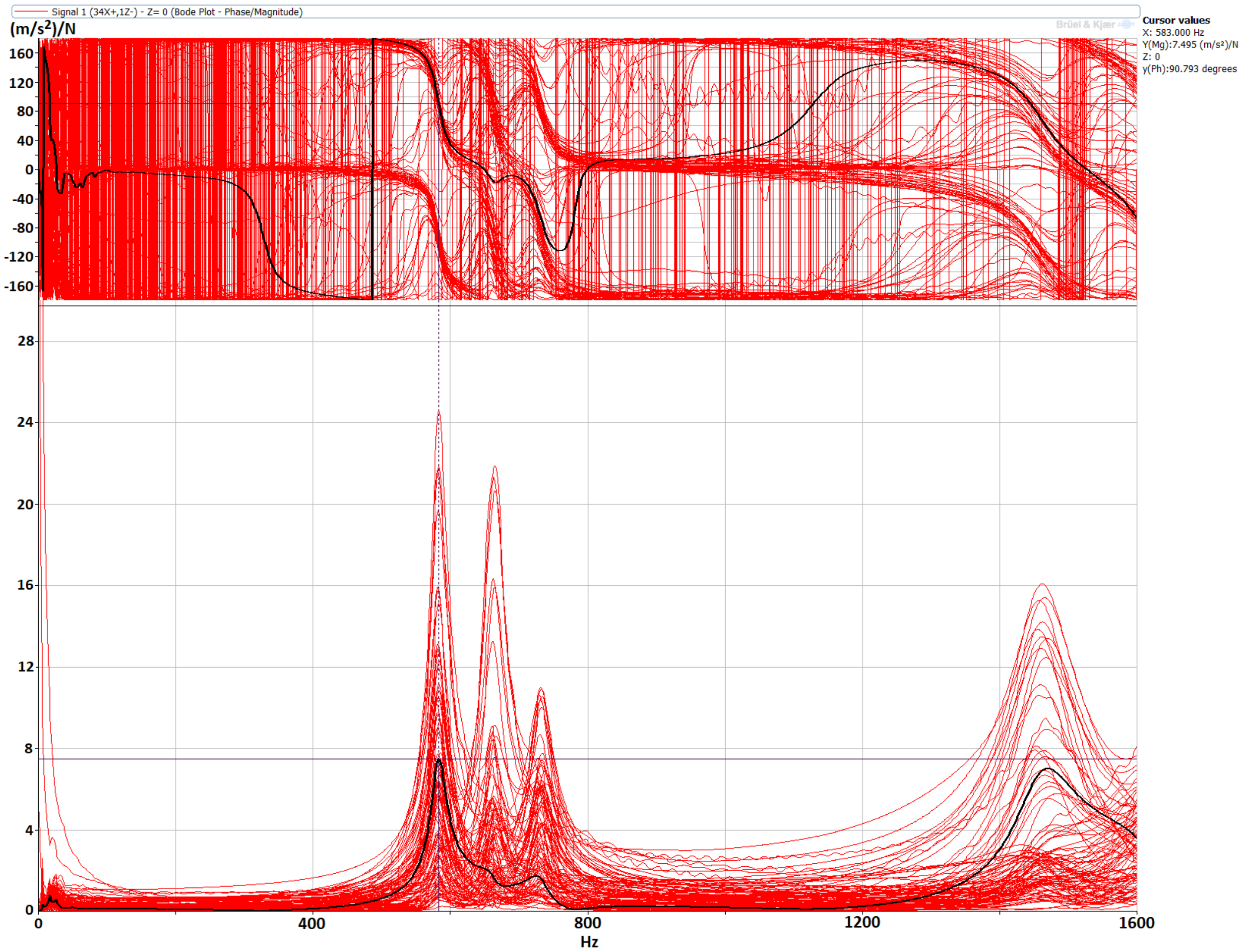

Fig. 2: Bovine femur - Bode diagram (amplitude and phase) of all measured transfer functions.

4. Modal Analysis via FEM

Modal analysis via FEM was performed by Simcenter 3D 2512 sw. The same boundary conditions were used in the FEM calculation and experiment. Some results, i.e. modal shapes and frequencies, are presented Fig. 3 and Tab. 2.

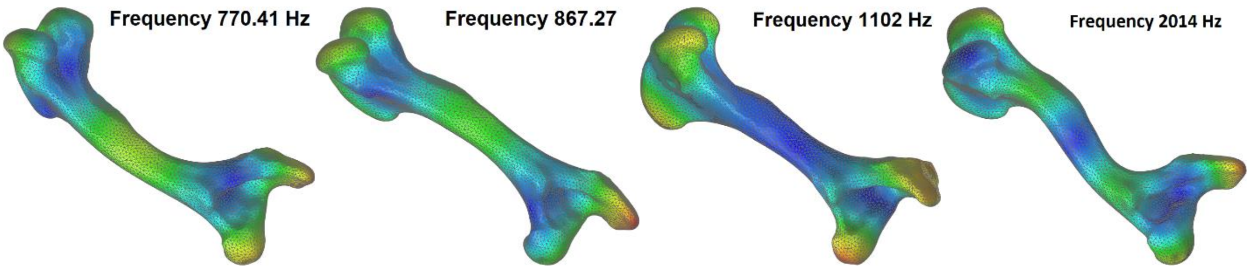

Fig. 3: Bovine femur (deformed structure) – Modal shapes for mode 1, 2, 3 and 4.

Tab. 2: Bovine femur – Results of FEM.

Mode	Frequency /Hz/
1	770.41
2	867.27
3	1102
4	2014
5	2179

5. Conclusions

A bovine femur from a cadaver was used to create the anatomical CAF/FEM model that relatively well respects the inhomogeneity in the distribution of density and elastic modulus. The modal analysis was performed using experiments and FEM. At first sight, the natural frequencies obtained by these two approaches do not match very well, see Tab. 1 and 2, which is also important information. The differences are primarily due to the complicated anisotropy and inhomogeneities of real bone, as well as the limitations of experiments and FEM. For these reasons, it is advisable to continue investigating this issue.

Acknowledgement

This work was supported by Specific Research "Computational and Experimental Modeling in Applied Mechanics and Biomechanics" (SP2025/048).

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