Modal Analysis of Humerus Bone Fracture With Fixed-Fixed Boundary Condition Based on Finite Element Analysis

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Abstract

Resonance phenomena suggests that loads closed to the natural frequencies could cause fractures in parts. The aim of the analysis of humerus bone is to find the natural frequencies and natural vibration modes of humerus bone. For the analysis of the bone, scanning results of a person's bone transferred to the Solidworks software and 3-D model of it is obtained. The 3-D model imported to ANSYS software for Finite Element Analysis (FEA) in the fixed-fixed boundary condition of the bone. Different Young's Modulus properties (Poisson ratio, Density constant) available in the literature are used for the humerus bone in the FEA. Natural frequencies and mode shapes are found. They are compared with other studies available in the literature.

Key words: humerus bone, finite element analysis, natural frequencies

1. Introduction

Human body exposures to the vibrations that called human vibrations. One of them is the Whole Body Vibrations (WBV) and other is Hand Arm Vibrations (HAV). WBV studies interested in cases when all parts of body exposure to vibration like bus driving [1]. HAV occur in hand and arms of people because of the high rpm vibrating machines [2]. HAV can lead to HAV syndrome. This is a hazard occurring ever since the usage of the hand power tools. These tools can be more hazardous if they vibrates closed to the natural frequencies of the bones in human body. There are several works about human vibrations and their hazardous effects [3,4].

Humerus bone is the bone located between shoulder and elbow. Humerus is connected to shoulder joint from region that called carpet humerus. There is a part called throclea humeri in the lower side of the humerus [5].

Experimental and analysis studies about human bones like femur and humerus are available in the literature. Adewusi et al. [6] studied on hand-arm system as a whole. They derived natural frequencies and mode shapes using FEA model of the human hand arm system. There were two boundary conditions which were fixed shoulder and shoulder with trunk to permit shoulder motion. Khalil et al. obtained natural frequencies and mode shapes of femur bone using experimental methods. A mathematical model that constructed with 59 joint segments was analysed with transfer matrix technique. They found first 20 natural frequencies in a range of 20

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Hz - 8 kHz [7]. Zadpoor studied on Humerus bone for different boundary conditions and for different scales of the bone dimensions. He modelled the bone as a cylinder with two hemispheres for simplicity of problem. Clamped, free and simply supported boundary conditions were used in the study. He stated that natural frequencies increased with increasing constraints, decreased with enlargement of the dimensions of the bone [8]. Kumar et al. studied FEA of the femur and humerus bones and found natural frequencies and mode shapes. Kumar studied on actual femur bone [9] but humerus bone model was not actual model [10] like Zadpoor studied using similar model and mechanical properties for bone [8]. He compared his results with experimental study of Khalil et al. obtained on femur bone [7]. The outcome of the study showed that fixed-fixed condition gives more closed results to the experimental study than free-free condition. There are several other studies about FEA of human bone [11-13].

The experimental results of Khalil et al. is between 250 and 7300 Hz for the first 20 natural frequencies of the femur bone [7]. On the other hand Kumar et al. studied it for different two boundary conditions. For free-free condition the range is between 0 - 1381.1 Hz and for fixed-fixed condition is between 1211 - 7856.4 Hz. Fixed-fixed condition was taken more appropriate because they are closed to the experimental results [9]. Kumar also studied these for humerus bone and found the frequencies between 0-1185.3 for free-free and between 943.36-7703.9 Hz for fixed-fixed conditions which are so closed to femur bone results [10].

In this study, we performed FEA and found natural frequencies and mode shapes of an actual model of the humerus bone in the fixed-fixed boundary condition.

2. Modelling

Actual model of Humerus Bone is obtained by Material's Interactive Medical Image Control System (MIMICS) software using Computed Tomography (CT) scanning images. MIMICS has different parts to edit CT images. Reverse engineering software is important here to make necessary improvements. For detailed information about scanning with MIMICS you can see [5]. After obtaining 3D model by using MIMICS software, it is imported to Solidworks. Solidworks data is imported to ANSYS 15 software for the FEA.

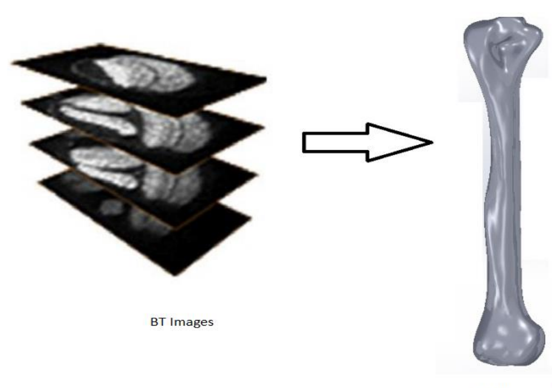

Figure 1. 3D model of Humerus bone

Modelling the humerus bone for analysis is very difficult because of the complex shape of the bone. Unlike the studies available in the literature bone is an actual humerus bone of a person in this study. Dimensions of the humerus bone are closed to the dimensions of the bone in [10].

3. Analysis

The modal analysis is performed for the humerus bone to find natural frequencies in ANSYS software. It's difficult to give actual boundary conditions from actual places of the bone because of the complex structure of the human body. Three different boundary conditions were used for the modal analysis in the literature to compare. Fixed-fixed, simply-simply and free-free conditions were solved and results were given in details. In fixed-fixed conditions all degrees of freedom (DOF) are constrained when in simply-simply boundary condition only displacements are set to zero. In free-free conditions all DOF are free to move, there is no constraints for the bone. Zadpoor studied all of these three boundary conditions and found that simply-simply and fixed-fixed boundary conditions give very closed results to each other[8]. Free-free condition is studied also in some studies and found that this is not appropriate for the actual bone conditions.

While considering humerus bone can make rotational motion, simply-simply boundary condition can be more appropriate than fixed-fixed condition. Even so, fixed-fixed boundary condition were performed in the literature instead of simply-simply condition for simplicity of the problem. In this study, fixed-fixed boundary condition is used because there is no significant difference with the simply supported condition. The constraints are given to the bone where it is subjected to the other parts of the body (shoulder and elbow).

There are three mechanical properties to be used in the FEA which are Young's modulus, bone density and Poisson ratio. Different Young's modulus are used in this study that are 14 GPa, 15 GPa, 17.2 GPa, 18.6 GPa, 20 GPa and an orthotropic elasticity($E_x=E_z=7$, $E_y=11.5$, $G_{xy}=G_{yz}=3.5$). Density is assumed to be 1900 kg/m^3 and Poisson ratio to be 0.3.

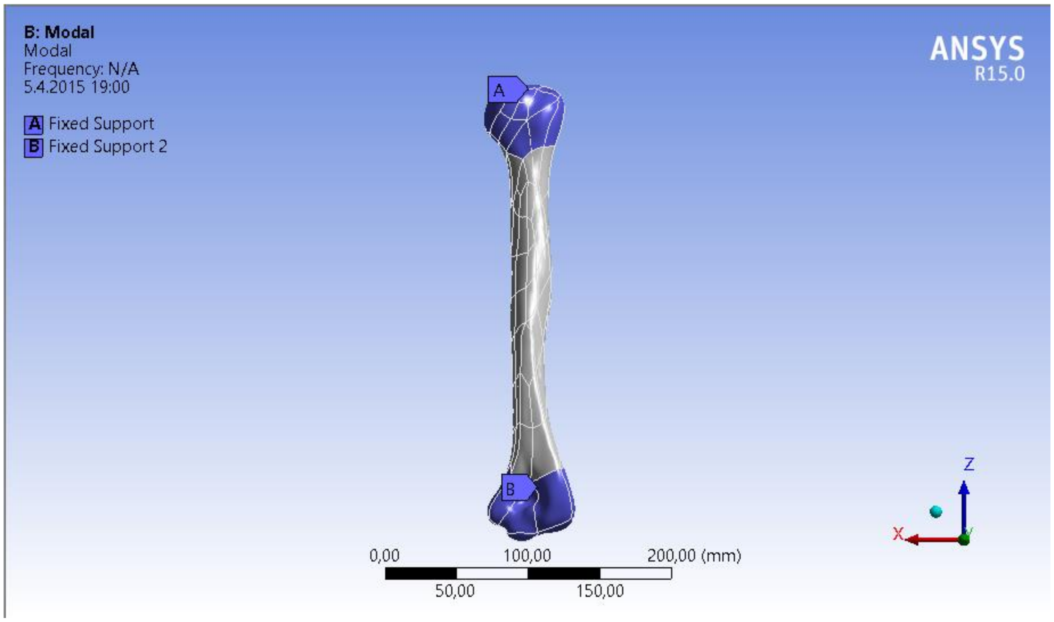

Figure 2. Boundary conditions of the humerus bone

4. Results and Discussion

In the fixed-fixed boundary conditions, natural frequencies are found in the range of 1243.5-8599.6 Hz for the Young's modulus of 17.2 GPa. The mode shapes are found also for this value and given in Figure 3. Generally the bone was assumed to be isotropic material but there were some studies to give orthotropic elasticity values. Six different modulus of elasticity (five isotropic, one orthotropic) are used for the humerus bone and found that natural frequencies of the bone increased with increasing values of elasticity. The natural frequencies according to Young's modulus are given in Table 1.

Table 1. Natural Frequencies for Different Young's Modulus

		Young's modulus(GPa)					
		14	15	17.2	18.6	20	Ex=Ez=7 Ey=11.5 Gxy=Gyz=3.5
Natural Frequencies (Hz)	1	1121.8	1161.2	1243.5	1293.1	1340.9	815.93
	2	1233.6	1276.9	1367.3	1421.9	1474.4	895.81
	3	2853.2	2953.4	3162.5	3288.7	3410.3	2091.9
	4	3060.5	3168	3392.3	3527.7	3658.1	2250.9
	5	3772.9	3905.3	4181.9	4348.8	4509.5	3027.2
	6	5074.3	5252.4	5624.4	5848.8	6064.9	3755.9
	7	5389.7	5578.9	5974	6212.4	6441.9	3995.4
	8	5839.7	6044.7	6472.8	6731.1	6979.8	4192.7
	9	7343.6	7601.4	8139.8	8464.6	8777.3	5775.7
	10	7758.5	8030.8	8599.6	8942.7	9273.2	5913.2

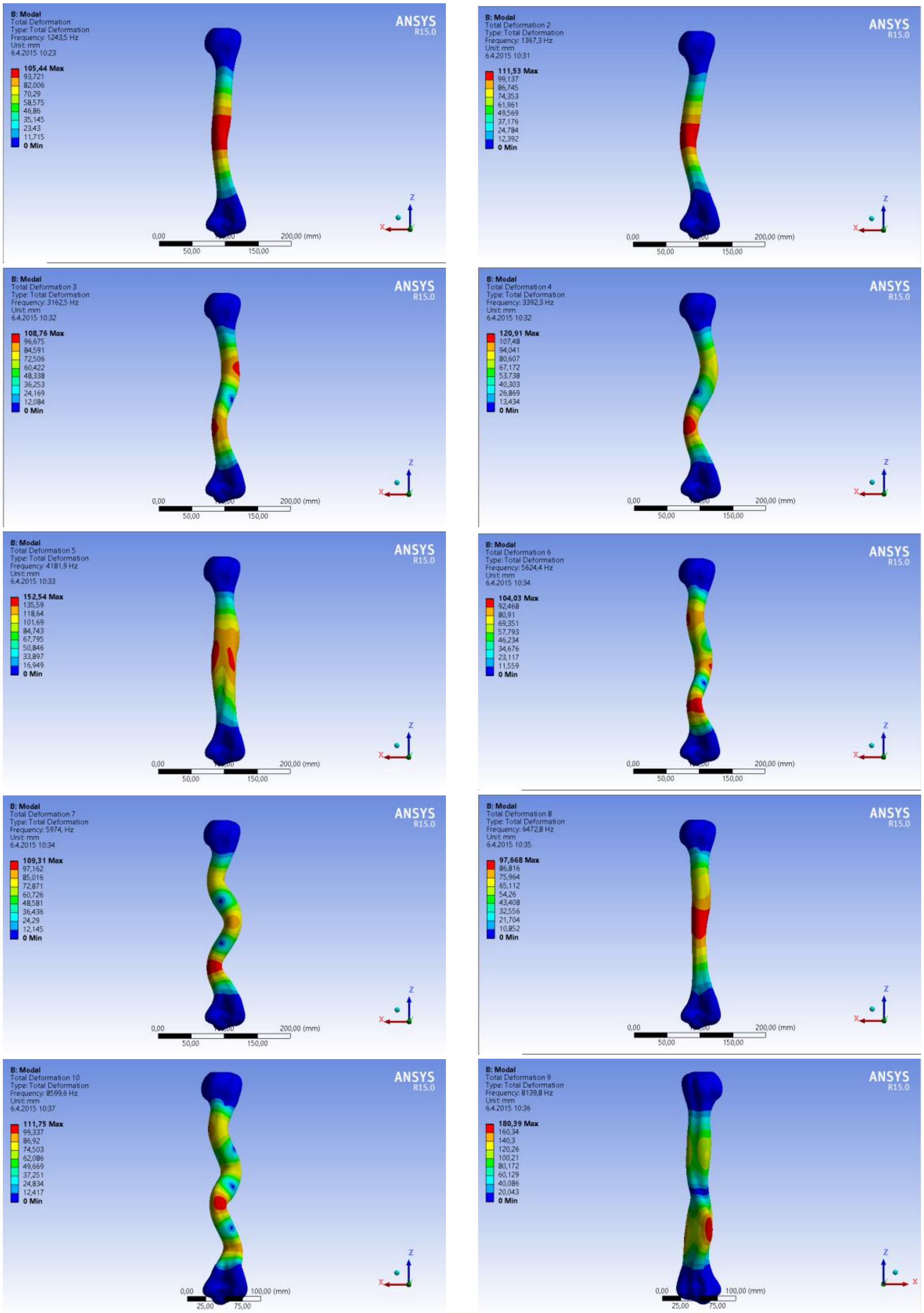

Figure 3. Mode shapes according to natural frequencies

In the studies of Zadpoor and Kumar et al., there were different results for the natural frequencies. Kumar et al. found in the range of 943.36 to 7703.9 Hz while Zadpoor found them between 534.32 and 4665.6 Hz. Zadpoor studied this bone with 3 different scale of the dimensions without giving the dimensions that were used. The natural frequencies were increased with decreasing dimensions and this is the possible reason of the differences between two studies. Kumar et al. give his dimensions in their study which are not so far from our actual bone model.

A system makes different motions in different resonance conditions which are called mode shapes of the system. Mode numbers and corresponding natural frequencies are given in the figures up to 10th natural frequency. The external loadings or excitations shouldn't be matched with the any of the natural frequencies. Thus, any machines that produces the external excitations should be designed according to these conditions. For under any excitation matching with natural frequencies, the red colored regions in the figures give where the maximum displacements will occur in the bone. For example; in the first mode shape the fracture will occur most likely in the middle of the bone.

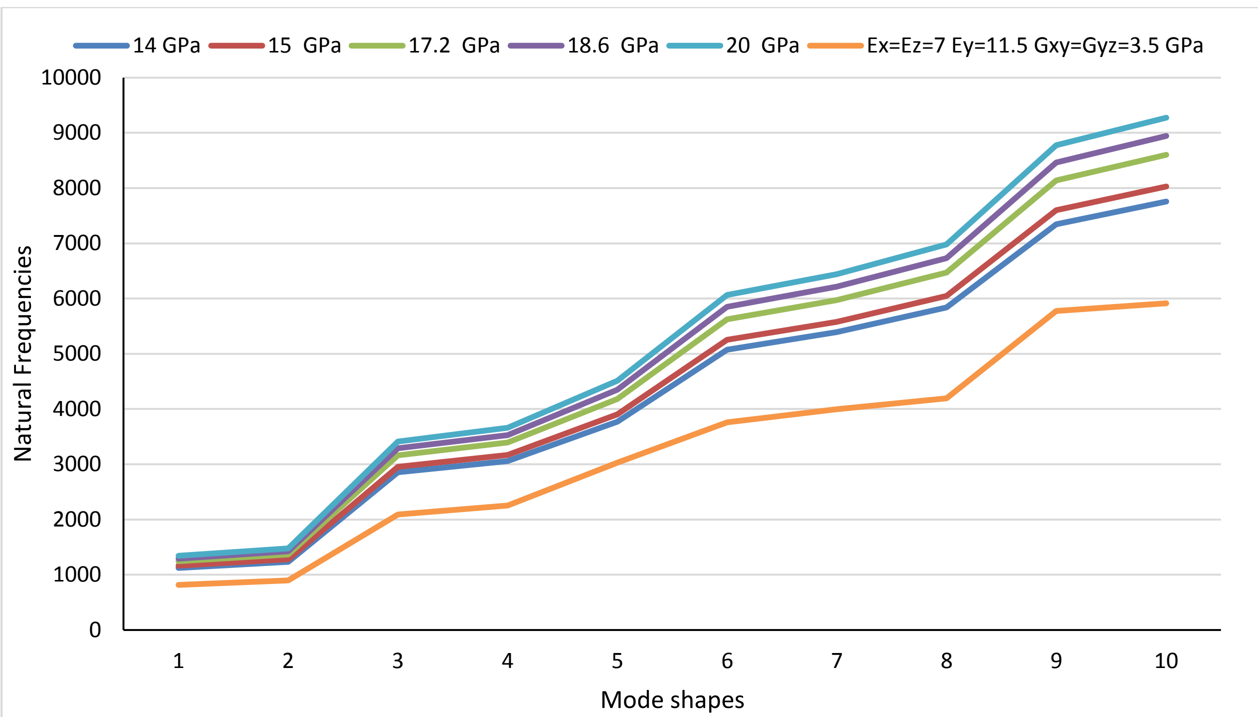

Figure 4. Change of natural frequencies according to different Young's modulus

Conclusion

The natural frequencies and mode shapes are found for a humerus bone model in this study. Because of resonance phenomena, it's important to find actual natural frequencies of the bones to avoid from these frequencies while designing machines that produce external excitations or loads to the hands and arms of the people. The humerus model used in this analysis is a real model unlike the others available in the literature. Also, different Young's modulus values are used to see how the bone will be affected. As seen from the Figure 4, the bigger values of Young's modulus give bigger values of natural frequencies in all modes. The study can be improved by studying on different people's humerus bones to get more results and compare.

References

[1] Lewis CA, Johnson PW. Whole-body vibration exposure in metropolitan bus drivers. Occupational medicine-oxford. 2012; 62; 519-524.

[2] Hagberg M. Clinical assessment of musculoskeletal disorders in workers exposed to hand-arm vibrations. International archives of occupational and environmental health. 2002; 75; 97-105.

[3] Barregard L, Ehrenström L, Marcus K. Hand-arm vibration syndrome in Swedish car mechanics. Occup. Environ. Med. 2003; 60; 287–294.

[4] Sonya H Bylund, Lage Burström, Anders Knutsson. A descriptive study of women injured by hand–arm vibration. The annals of occupational hygiene. 2001; 46; 299-307.

[5] Kaya Nuriye Nur. İnsan kolu humerus kemiği için sonlu elemanlar modeli ve analizi. Gazi University, Graduate School of Natural and Applied Sciences; 2003.

[6] Adewusi S, Thomas M, Vu VH and Li W. Modal parameters of the human hand-arm using finite element and operational modal analysis. 3 ième Congrès International sur l'Ingénierie des Risques Industriels. 2013.

[7] Khalil TB, Viano DC, Larry Taber. Vibrational characteristics of the embalmed human femur. journal of sound and vibration. 1981; 75; 417-436.

[8] Zadpoor AA. Finite element method analysis of human hand arm vibrations. Int. J. Sci. Res. 2006; 16; 391-395.

[9] Ashwani Kumar, Himanshu jaiswal, Tarun Garg, Pravin P Patil. Free Vibration Modes Analysis of Femur Bone Fracture Using Varying Boundary Conditions Based on FEA. Procedia Materials Science. 2014; 6; 1593–1599.

[10] Ashwani Kumar, Deepak Prasad Mamgain, Himanshu Jaiswal, Pravin P Patil. Modal Analysis of Hand-Arm Vibration (Humerus Bone) for Biodynamic Response Using Varying Boundary Conditions Based on FEA. Intelligent Computing, Communication and Devices. Advances in Intelligent Systems and Computing. 2015; 308; 169-176.

[11] Gupta A, Tse KM. Vibration analysis of femur bone using elmer. Journal of Engineering Science and Technology Special Issue on ICMTEA 2013 Conference. 2014; 12–19.

[12] Neelesh Sharma, Brijesh Yadav. Free vibration analysis of humerus bone fracture with varying boundary condition based on FEA. International Journal of Advanced Technology & Engineering Research (IJATER) 1st International Conference on Research in Science, Engineering & Management IOCRSEM. 2014.

[13] Campoli G, Baka N, Kaptein BL, Valstar ER, Zachowc S, Weinans H, Zadpoor AA. Relationship between the shape and density distribution of the femur and its natural frequencies of vibration. Journal of Biomechanics. 2014; 47; 3334–3343.