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Vibration Impact on Human Body Using Analytical and Numerical Modelling

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Abstract:

A three dimensional finite element model is developed and analysed using computational software. A 15degrees of freedom (DOF) lumped parameter model is made has continuous model and considered for modal analysis using finite element method. The human body is made up of 3 dimensional ellipsoids with 5 percent truncation. The material properties have been assigned from 15 DOF lumped parameter model and natural frequencies obtained for the developed model are compared with finite element method results obtained in the past literatures. Principle resonance frequency of the human body obtained from finite element method is 6.45 Hz. Mode shapes and deformations due to whole body vibration in all resonance frequency ranges are numerically obtained and found to be within the range of available literature. The model is also analysed analytically by solving governing equations for Eigen values and natural frequencies.

***Keywords* — Whole body vibrations, Principal resonance, Mode shapes, Natural frequency.**

I. INTRODUCTION

The human body is a complex structure, influenced by vibrations in daily life activities (transportation, walking, running, working etc) in many ways and the responses are mainly dependent on the frequency, amplitude, and duration of exposure. Other factors may include the direction of vibration input, location and mass of different body segments. Both analytical and computational techniques have been used to study the vibration response of human body. Numerous models of biomechanical responses to whole body vibrations (WBV) have been proposed, with different idealisations of the body structure. The models can be broadly categorised into three types, i.e., lumped parameter models, continuum models and discrete models, out of which lumped parameter models have been considered in most of the research studies.

Literature shows that most of the lumped parameter models are one-dimensional as compared to three-dimensional models. A first resonance frequency of 5.9 Hz was measured for ‘standing erect with stiff knees’ posture in vertical sinusoidal vibrations from 1 to 20 Hz (2). The frequencies of standing subjects have been found to vary over a wide range from 4 to 16 Hz, which has been attributed to changing the stiffness by subjects by tensing their leg muscles or bending their knees (3).Resonant frequencies of standing man in the range of 8 to 10 Hz have been also reported elsewhere. Edwards and Lange measured the mechanical impedance of two standing male subjects with three different magnitudes of vertical sinusoidal vibration, viz., 0.2, 0.35 and 0.5 g, in the frequency range from 1 to 20 Hz. A principal resonance was found to occur at a frequency between 4 to 5 Hz and a second resonance was located in the range 11 to 15 Hz with a 'normal standing posture' with all magnitudes of vibration. The mechanical impedances of twenty standing subjects in various postures were investigated by Miwa.

II. THE HUMAN BODY MODEL WITH STANDING POSTURE

The standing posture model in 3-Dimension is developed with five percent truncated ellipsoidal segments using anthropometric data and also mass, stiffness values for these segments are considered from Nigam and Malik (1987). The Young's modulus is derived from Nigam and Malik (4) using elastic moduli of bones and tissues.

III THREE DIMENSIONAL GEOMETRY USING ELLIPSIDS

"The geometric models of the human body take part an important role in analysing the human response to the vibratory platform in industries, vehicles and also in product design, allowing industrial products such as cars, furniture and clothing to be custom-designed for an individual's body shape" S.Bischoff and L. Kobbelt, (2002).The present model is constructed in 3D geometry based on Nigam and Malik, (1987).These solid ellipsoidal models define the volume of the object they represent, and hence density of each part is been calculated. J. A. Bartz and C. R. Gianotti, (1975) suggested that the human body in reality is not a homogeneous mass, the bulk (average) densities of different body segments are nearly the same.

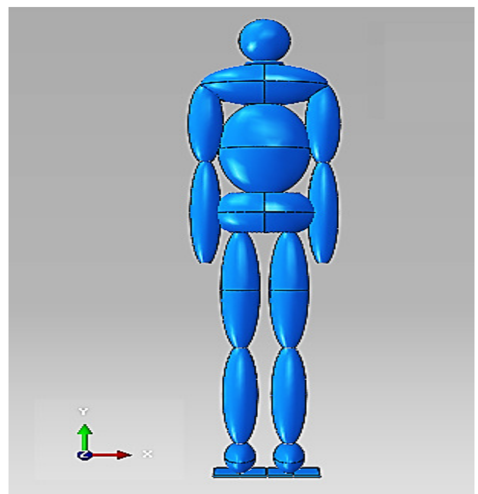


Fig. 3.1(a) Finite element human model

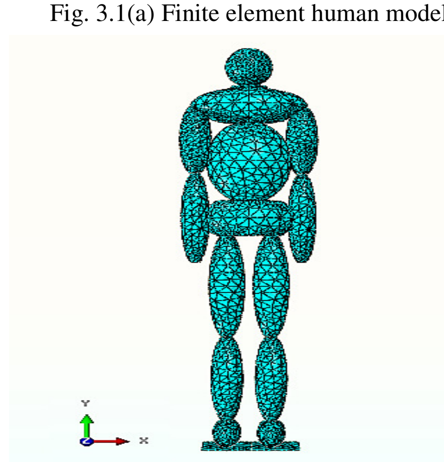


Fig. 3.1(b) Quadrilateral C3D10 Hexahedron Mesh

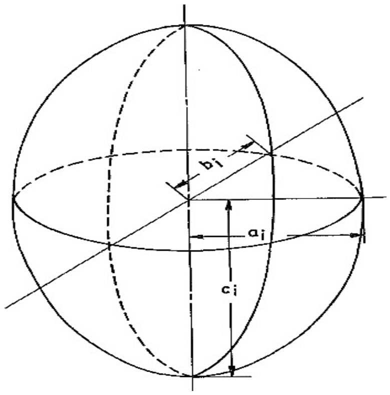


Fig. 3.1(C) Ellipsoid

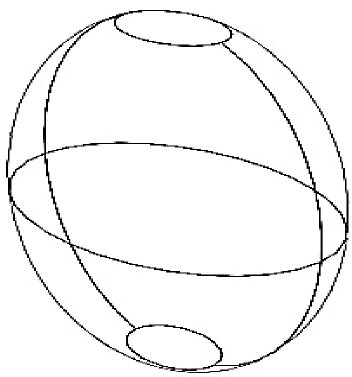
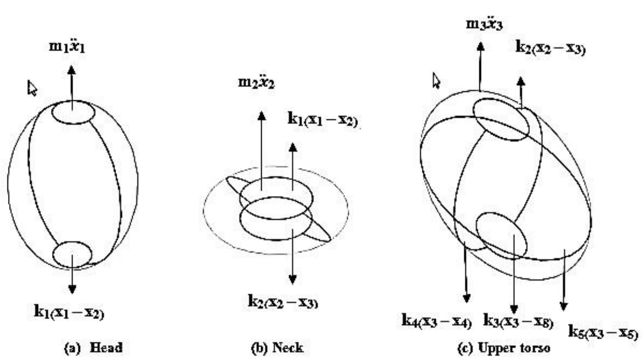


Fig. 3.1(d) truncated ellipsoid with 5 %



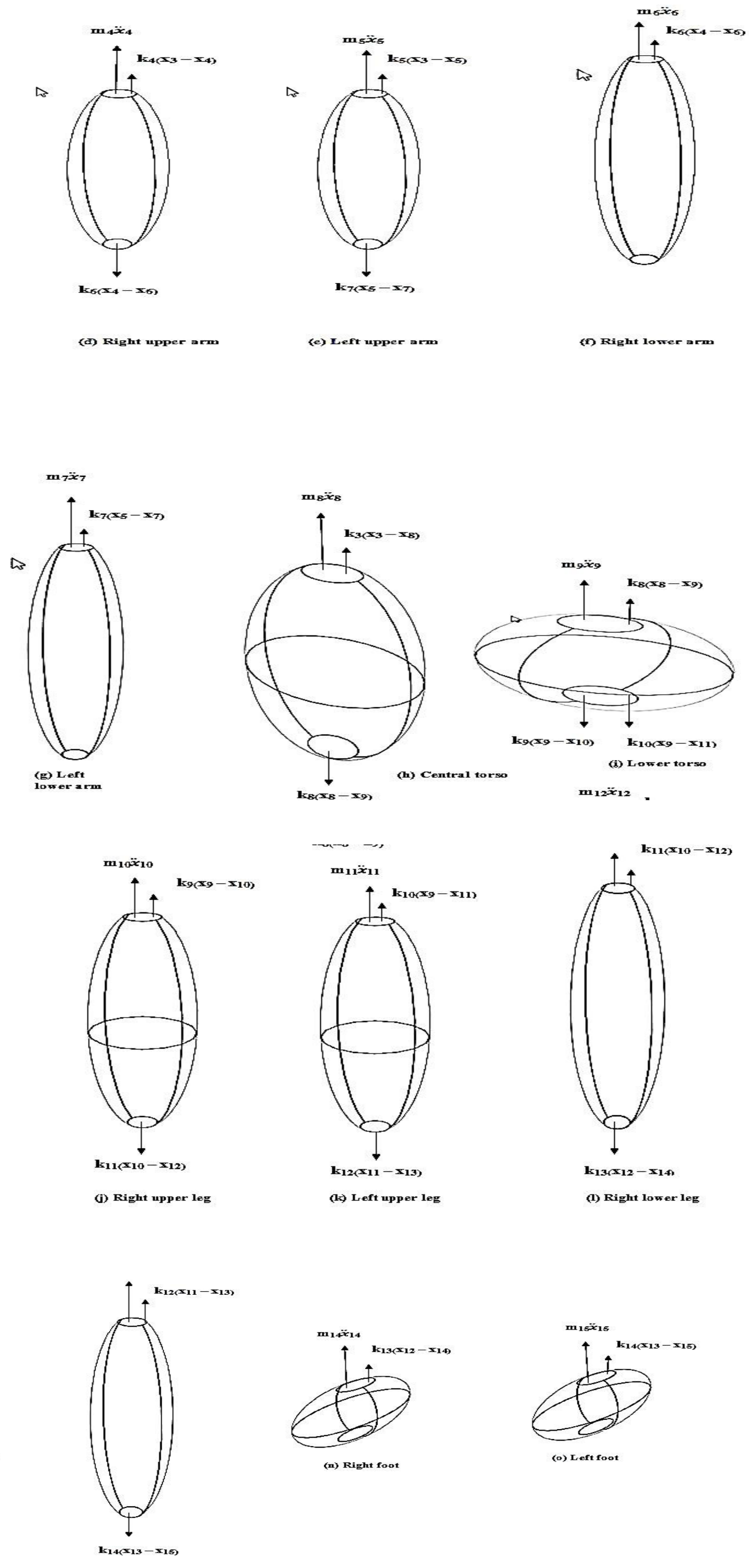


Fig. 3.1(e) Human body parts

III. A. Equations of motion

$m_{11} + k_1 x_1 - k_1 x_2 = 0$ -- (1)

$m_{22} - k_1 x_1 + (k_1 + k_2) x_2 - k_2 x_3 = 0$ -- (2)

$m_{33} - k_2 x_2 + (k_2 + k_3 + k_4 + k_5) x_3 - k_4 x_4 - k_5 x_5 - k_3 x_8 = 0$ -- (3)

$m_{44} - k_4 x_3 + (k_4 + k_6) x_4 - k_4 x_4 - k_6 x_6 = 0$ -- (4)

$m_{55} - k_5 x_3 + (k_5 + k_7) x_5 - k_7 x_7 = 0$ -- (5)

$m_{66} - k_6 x_4 + k_6 x_6 = 0$ -- (6)

$m_{77} - k_7 x_5 + k_7 x_7 = 0$ -- (7)

$m_{88} - k_3 x_3 + (k_3 + k_8) x_8 - k_8 x_9 = 0$ -- (8)

$m_{99} - k_8 x_8 + (k_8 + k_9 + k_{10}) x_9 - k_9 x_{10} - k_{10} x_{11} = 0$ - (9)

$m_{1010} - k_9 x_9 + (k_9 + k_{11}) x_{10} - k_{11} x_{12} = 0$ -- (10)

$m_{1111} - k_{10} x_9 + (k_{10} + k_{12}) x_{11} - k_{12} x_{13} = 0$ -- (11)

$m_{1212} - k_{11} x_{10} + (k_{11} + k_{13}) x_{12} - k_{13} x_{14} = 0$ -- (12)

$m_{1313} - k_{12} x_{11} + (k_{12} + k_{14}) x_{13} - k_{14} x_{15} = 0$ -- (13)

$m_{1414} - k_{13} x_{12} + k_{13} x_{14} = 0$ -- (14)

$m_{1515} - k_{14} x_{13} + k_{14} x_{15} = 0$ -- (15)

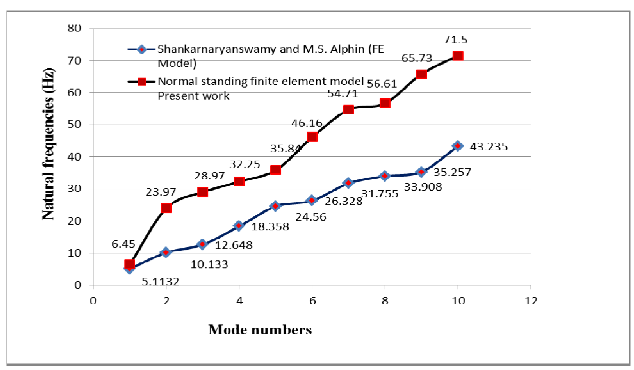
III.B. Analytical method

The mathematical model consisting of fifteen degree of freedom standing human body is been solved for obtaining natural frequencies. In the model, mass of each rigid element equals the mass of the corresponding segments (4). The model is considered with the case of free vibrations with mass and stiffness only. Where, [M] and [K] are respectively mass and stiffness matrices of order 15 X 15. For solving 15 X15 matrices MATLAB is used and Eigen roots were obtained. The computed natural frequencies of the model are as follows:

f_1 =0 Hz, f_2 = 13.82 Hz, f_3=14.35 Hz, f_4 = 23.92Hz, f_5 = 25.22 Hz, f_6 = 28.77 Hz, f_7 = 29.53 Hz, f_8 = 40.29 Hz, f_9 = 53.32 Hz, f_{10} = 58.27 Hz, f_{11} = 58.29 Hz, f_{12} =79.81 Hz, f_{13} = 165.6 Hz, f_{14} = 165.6 Hz, f_{15} = 507.9 Hz.

IV.MODAL ANALYSIS OF HUMAN BODY MODEL (FEA)

Modal analysis has become a frequently used method for studying the dynamic behaviour of mechanical structures. Kitazaki and Griffin (8) used beam, spring and mass elements for analysing the spine, viscera, head, pelvis and buttocks tissue in mid-sagittal plane and found the resonance frequency at 5 Hz. Matsumoto and Griffin compared the dynamic responses of the human body in standing position and sitting position and reported that the apparent mass occurs in the 5–6 Hz frequency range. Arjmand and Shirazi-Adl studied using thoracic lumbar finite element modal to determine muscle forces, spinal loads, and stability margin in isometric forward flexion tasks. The three-dimensional finite element model of the pelvis-femur complex was developed by Majumder et al., using a wide range of mechanical properties in the bone to study the simulation of actual impact situations due to sideway fall, and to examine hip fracture conditions of other impact series. Bourdet and Willinger, identified a five original lumped parameters trunk model and torso lumped parameter model.



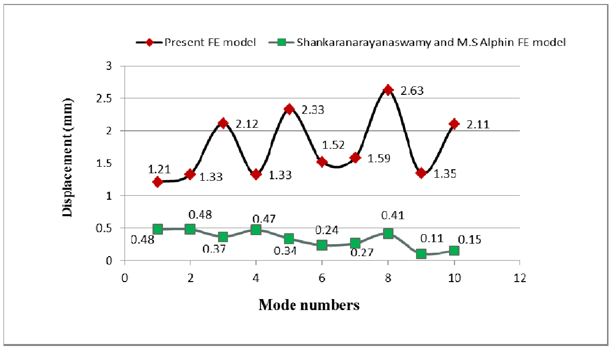


Fig 4, Comparison of natural frequencies with Shankaranarayna swamy and M. S Alphine (FE model)

V. CONCLUSIONS

The human body is established continuum model using finite element method (FEM) by taking the 5% truncated 3 dimensional ellipsoids with different body mass segments and analyzed for free vibration and obtained natural frequencies and displacement values for 15 modes. The results are validated with experimental values from literature and with other finite element models.The FEA technique significantly very effective to with discretization of elements and to make changes in parameters, conditions with lesser time and it reduces the cost of experimentation with its simulation capabilities to analyse the model. The iterations and optimization can be made to make changes in the model. From the results it is been observed resonance peak occurs at 6.45 Hz and the last mode gives the frequency of 130.95 Hz with the maximum deflection of upper leg 2.71 mm. The deflection is reducing in upper parts of the body with increase in frequency, whereas the deflection is increasing in the lower parts of the body with increase in frequency. The stiffness value plays a vital role in obtaining resonance frequency in the range of 4 – 6.5 Hz. In order to improve the evaluation of FEM models the exploration of work are still necessary on individual subject due to inter subject variability in the real working condition. Future research should need to be worked on nonlinear models, rotational motions of the body and on the assumption of Young's modulus can be consider the human model for stress stain analysis.

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