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Modelling and Simulation of 3-DOF Mass Spring System Equivalent of 3-Storey Building by Using ANSYS 18.1

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Abstract— The purpose of the work is to obtain Natural Frequencies and Mode Shapes of 3- storey building by an equivalent mass- spring system, and demonstrate the modeling and simulation of this MDOF mass- spring system to obtain its first 3 natural frequencies and mode shape. In whole procedure ANSYS 18.1 has been used. The analytical analysis of natural frequencies was used to compare the numerical results obtained by ANSYS 18.1 to validate the results.

Index Terms— Mass-spring, ANSYS, Natural frequencies, Mode Shape MDOF, Modeling, Simulation.

1 Introduction

THE mode shapes, natural frequencies of 3-storey building established as equivalent 3-DOF mass-spring system. The study of this work is useful for the designing of structures subjected to earthquake and dynamic loading. The Vibrational analysis, Response spectrum analysis will be easily worked after determine the natural frequencies and mode shapes.

1.1 Purpose of study

The purpose of the study is to obtain the first 3 natural frequencies and mode shapes of 3- storey building equivalent as MDOF mass-spring system. The modeling and simulation was done by using ANSYS 18.1

1.2 Benefit of study

The benefit of study is to predict the natural frequencies of vibration and excitation response of any structure like buildings, bridges, water tanks and small and big structures of any metal.

2 METHODOLOGY

The simulation process was carried out by using of ANSYS 18.1 and the theoretical analysis was used to validate the results obtained from ANSYS 18.1 the method has been carried out below.

2.1 The theoretical Analysis

The shown fig (2.1) is a 3- storey building with their masses on each floor and the corresponding equivalent mass-spring system is shown in fig (2.2)

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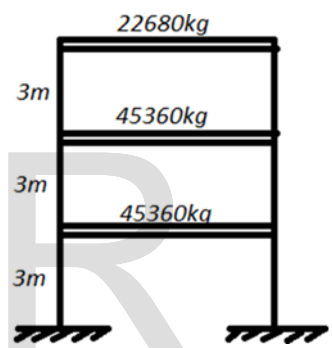

Fig (2.1):- 3-storey building

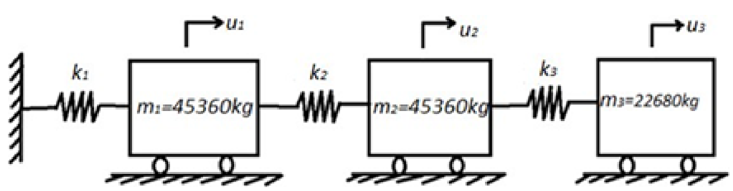

Fig (2.2):- Equivalent system

The equivalent system fig (2.1) shows three degree of freedom (3-DOF) system.

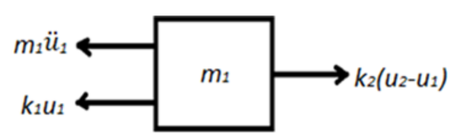

Fig (2.3):- Free body diagram of mass m_1

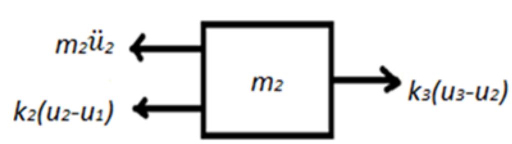

Fig (2.4):- Free body diagram of mass m_2

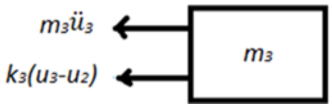

Fig (2.5):- Free body diagram of mass m_3

Masses is given as m_1 = 45360 kg, m_2 = 45360 kg, m_3 = 22680 kg

$k_1 = k_2 = k_3$ = 2×12EI/L = (2×12×4.5×10^6)/ (3^3) = 4×10^6 N/m

The following equations obtained from free body diagram.

$$m_1\ddot{u}_1 + (k_1 + k_2)u_1 - k_2u_2 = 0 \quad \text{------ (1)}$$

$$m_2\ddot{u}_2 - k_2u_1 + (k_2 + k_3)u_2 - k_3u_3 = 0 \quad \text{---- (2)}$$

$$m_3\ddot{u}_3 - k_3u_2 + k_3u_3 = 0 \quad \text{------ (3)}$$

Writing the equations (1), (2) and (3) into the equation of motion of an MDF system subjected to free vibration is given as

$$[M]\{\ddot{u}\} + [k]\{u\} = \{0\} \quad \text{------ (4)}$$

$$\begin{bmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{bmatrix}\begin{Bmatrix} \ddot{u}_1 \\ \ddot{u}_2 \\ \ddot{u}_3 \end{Bmatrix} + \begin{bmatrix} (k_1+k_2) & -k_2 & 0 \\ -k_2 & (k_2+k_3) & -k_3 \\ 0 & -k_3 & k_3 \end{bmatrix}\begin{Bmatrix} u_1 \\ u_2 \\ u_3 \end{Bmatrix} = 0$$

------- (5)

$$\begin{bmatrix} 45360 & 0 & 0 \\ 0 & 45360 & 0 \\ 0 & 0 & 22680 \end{bmatrix}\begin{Bmatrix} \ddot{u}_1 \\ \ddot{u}_2 \\ \ddot{u}_3 \end{Bmatrix} + 4\times10^6\begin{bmatrix} 2 & -1 & 0 \\ -1 & 2 & -1 \\ 0 & -1 & 1 \end{bmatrix}\begin{Bmatrix} u_1 \\ u_2 \\ u_3 \end{Bmatrix} = 0$$

-------- (6)

The characteristic equation is $(k) - (m)\omega_n^2 = 0$ ------- (7)

$$\left|4\times10^6\begin{bmatrix} 2 & -1 & 0 \\ -1 & 2 & -1 \\ 0 & -1 & 1 \end{bmatrix} - 1000\omega_n^2\begin{bmatrix} 45.36 & 0 & 0 \\ 0 & 45.36 & 0 \\ 0 & 0 & 22.68 \end{bmatrix}\right| = 0$$

------- (8)

$$\left|\begin{bmatrix} 2 & -1 & 0 \\ -1 & 2 & -1 \\ 0 & -1 & 1 \end{bmatrix} - 2.5\times10^{-4}\omega_n^2\begin{bmatrix} 45.36 & 0 & 0 \\ 0 & 45.36 & 0 \\ 0 & 0 & 22.68 \end{bmatrix}\right| = 0$$

------- (9)

Let $2.5\times10^{-4}\omega_n^2 = \lambda$ we get

$$\begin{vmatrix} (2-45.36\lambda) & -1 & 0 \\ -1 & (2-45.36\lambda) & -1 \\ 0 & -1 & (1-22.68\lambda) \end{vmatrix} = 0$$

------- (10)

Expanding the determinant, we get

$$46664.8\lambda^3 - 6172.59\lambda^2 + 204.12\lambda - 1 = 0 \quad \text{------- (11)}$$

Solving the above equation we get

$$\lambda_1 = 0.00590717$$

$$\lambda_2 = 0.0440917$$

$$\lambda_3 = 0.0822762$$

As we know that

$$\lambda = 2.5\times10^{-4}\omega_n^2$$

$$\lambda_1 = 0.00590717\omega_1^2$$

$$\frac{0.00590717}{2.5\times10^{-4}} = \omega_1^2$$

$$\omega_1 = 4.86094\ {rad}/{s} = 0.77\ Hz$$

$$\lambda_2 = 0.0440917\omega_2^2$$

$$\omega_2^2 = \frac{0.0440917}{2.5\times10^{-4}}$$

$$\omega_2 = 13.28031626\ {rad}/{s} = 2.11\ Hz$$

$$\lambda_3 = 0.0822762\omega_3^2$$

$$\omega_3^2 = \frac{0.0822762}{2.5\times10^{-4}}$$

$$\omega_3 = 18.14124582\ {rad}/{s} = 2.89\ Hz$$

The natural frequencies (or) Eigen values are

$$\omega_1 = 0.77\ Hz$$

$$\omega_2 = 2.11\ Hz$$

$$\omega_3 = 2.89\ Hz$$

2.2 Modeling and Simulation

2.2.1 Material and Geometry: -

Structural steel with density 7850 kg/m^3 used to make masses and young modulus and Poisson's ratio of steel is 2×10^11 Pa and 0.3 after that draw geometry by open Model dialog box from analysis systems of tool box and attach springs and provide stiffness value to all as 4×10^6 N/m

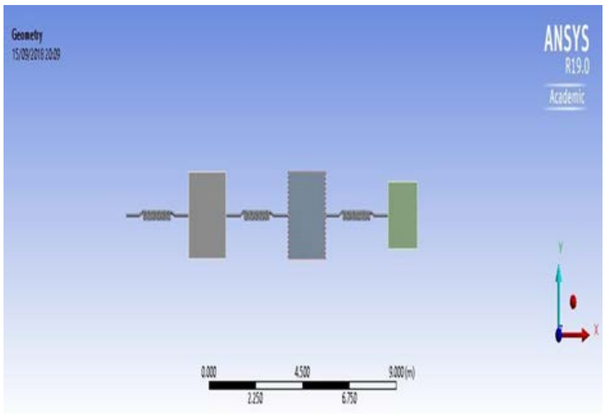

Fig (2.6):- The Solid Model

2.2.2 Meshing:-

Meshing divides the whole components into many small elements to distribute applied load uniformly to whole components. All faces were selected for mesh generation and total number of nodes and elements were observed as 4937 and 902 respectively.

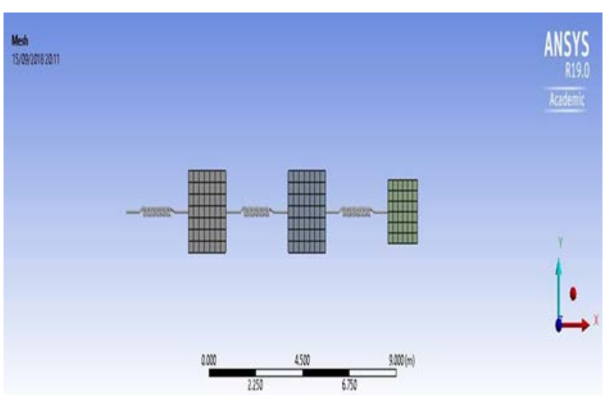

Fig (2.7):- Meshed model of mass-spring system

2.2.3 Boundary Conditions: -

Remote displacements 1, 2, 3 applied for mass1, 2 and 3 where X components taken as free for all three remote displacements.

3 REUSULTS AND DISCUSSION

The obtained frequency results shown below in the table

Table (1) Mode and Frequency

Mode	Frequency
1	0.77364
2	2.1136
3	2.8873

The first three mode shapes shown below in figures

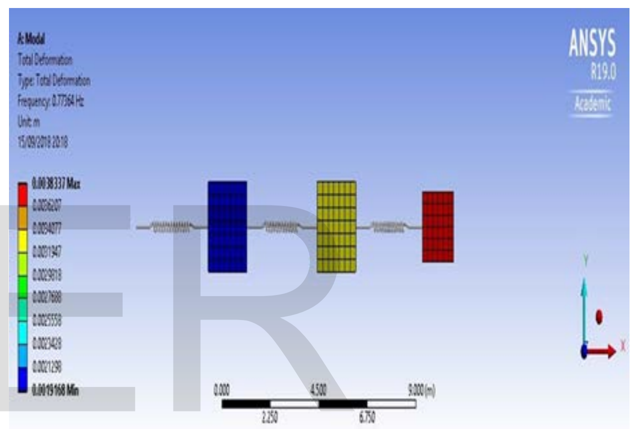

Fig (2.8):- Mode Shape 1

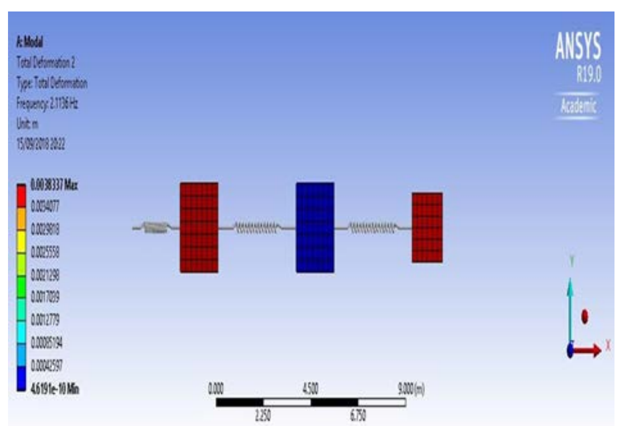

Fig (2.9):- Mode Shape 2

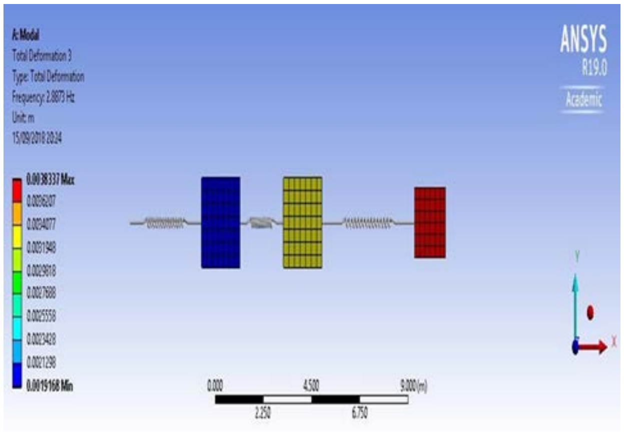

Fig (3):- Mode Shape 3

3.1 Comparison of Theoretical calculation and ANSYS:-

Table (2) results from theoretical calculation and ANSYS

	Theoretical value	ANSYS
Frequency 1 (Hz)	0.77	0.77364
Frequency 2 (Hz)	2.11	2.1136
Frequency 3 (Hz)	2.89	2.8873

3.2 Analysis of Results and Discussion:-

The ANSYS results almost matched with theoretical solved results. Hence solution from ANSYS is valid and acceptable.

4 CONCLUSIONS AND FUTURE SCOPE OF WORK

The ANSYS result shows that is possible to determine natural frequency and mode shapes of any multistory building by establishing equivalent mass-spring system. And the results obtained from ANSYS are almost matched with theoretical solved results. Therefore the ANSYS result is valid and acceptable, so it can be used for the determination of natural frequencies of SDOF and MDOF system.

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