Vibrational study of nanocomposites

6.1 Introduction

The objective of this work is to find the best possible carbon nanotube (C.N.T.) waviness inside a matrix composite beam and composite bridge is to achieve its highest natural frequencies while taking the C.N.T. volume fraction into account. To determine the optimum waviness under encastre boundary conditions and various vibration modes, a 3D F.E. model of the beam is created using ABAQUS and Python programming. The effects of wave number and waviness on mode shapes, natural frequencies, and associated beam stiffness are investigated, and the results are contrasted with those of a pure polymer beam, a composite beam made of straight C.N.T.s, and a nanobridge value. The optimal number of elements and nodes for the convergence research is currently being investigated, and it has been discovered that 19666 nodes are acceptable for producing accurate findings. The waviness impact of carbon nanotubes is substantially dependent on mode shapes, according to the results of the F.E. study. We find an increase in the basic natural Frequency as well as other relevant vibrational features. The third mode's natural frequency increases by 68.68, the fifth mode by 44.6, and the sixth mode by 62.4 when the waviness is reduced from 50 to 25, but there is almost negligible change in the other modes. When single-wave C.N.T.s are compared to multiwave C.N.T.s, the third mode has a higher frequency of 206.03 Hz, the fourth mode of 199.8 Hz, and the sixth mode of 478.6 Hz. The following comparison illustrates the outcomes of various waviness types, including single sine waviness, multi-waved C.N.T.s, straight C.N.T.s, and

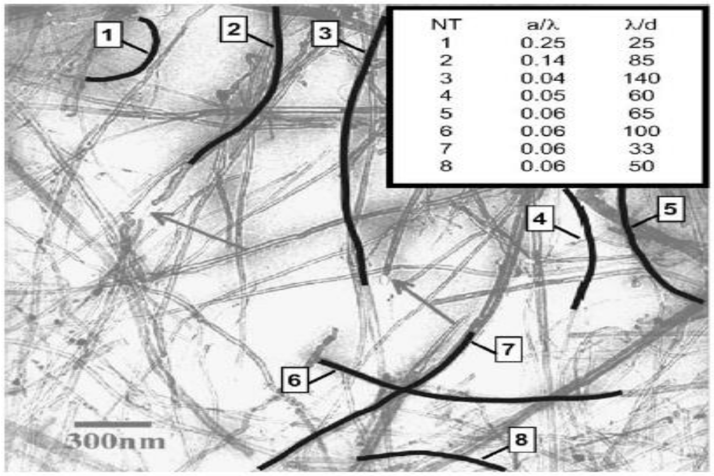


Figure 6.1. Approximate values for the wavelength ratio=λ/d and waviness,w=a/λ [130]

pristine matrix. The natural frequency of the CNTs reinforced nanocomposite matches the frequency of a neat matrix at the maximum degree of waviness of the CNTs fibre based nanocomposite. Additionally, adding more CNTs has no effect on the value of frequency. The outcome shown that the vibratory system may be accurately simulated by the finite element method (F.E.M.). The creative concept in this work is distinct in that it looks into how nanotube curvature affects vibrations in addition to looking into how resonance conditions of C.N.Ts do not raise the value of frequency. The outcome shown that the vibratory system can be accurately simulated by the finite element model. During design time it is important for material to possess high natural Frequency to avoid the failure caused due to different types of disturbances as for illustration bridges due to loaded by vehicles, people , wind etc. buildings, CCTV poles which is experiences disturbances by wind, earthquake etc. the classic example for resonant condition are Tacoma narrows bridge disaster. Very specific to this bridge the wind was blowing and at one particular of time the wind frequency matches with the bridge frequency and then there is excessive deformation in bridge and finally collapse so this is the real life resonant condition. The effect of nanotube curvature on vibrations and resonance condition of system, body or part made of composite material which had previously been studied by a number of scholars, and the influences of curvature on the natural Frequency and mode shape have also been detected when there is encastre boundary condition.

6.2 F.E. analysis Wavy CNTs-reinforced nanocomposite structure

The Finite Element method (F.E.M.) is a computational technique which helps in predicting the vibrational properties of C.N.T.s reinforced composite containing wavy C.N.T.s plus matrix. Wavy nature of carbon nano tube (C.N.T.s) in nano reinforced composite has been confirmed by numerous experiments [1,2]. Due to meshing problems and superfluous elements researchers conducted intricate processes to simulate wavy inclusions of C.N.T.s inside a matrix using finite element models. Usually it takes lots of computational time for meshing because of lesser amount of C.N.T.s in comparison with matrix. Therefore, researchers are preferring R.V.E. with lesser quantity of C.N.T.s instead of simulating large scale modeling of nanocomposites. Since this type of simulation and modeling do not capture fully the performance of nanostructure or nanocomposite, therefore increasing number of C.N.T.s inclusion is a good practice. To overcome such meshing difficulty, a set of beam elements is used containing 2 nodes and having 12 degree of freedom. The literature [133] modeled the C.N.T.s curvature by various profiles like sinusoidal, parabola and a circle’s arc and proves that the outcomes are insusceptible to the profile shape. An arbitrary C.N.T.s profile in a 2D matrix has been taken [181]. In this work the C.N.T.s waviness is expressed as a sinusoidal model as shown in Figure 6.2.

$$y = a\cos\left(\frac{2\pi z}{\lambda}\right) \tag{6.1}$$

Where, λ = wavelength, a = amplitude of wavy C.N.T.s and z = fiber axial direction. The nanotube waviness, W is defined as (a/λ) and the wavelength ratio as (λ/d); the approximate values for the highlighted C.N.T.s are given in Figure 6.2 and these experimental data are

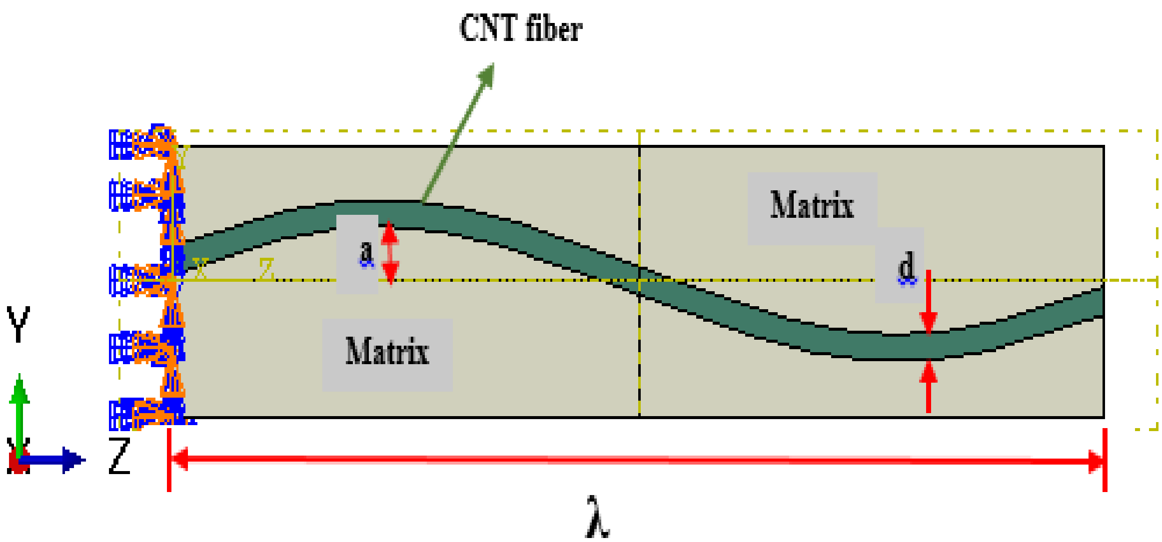


Figure 6.2. The model of the C.N.T.s reinforced composite.

collected from ref. [130]. A continuum, three dimensional, eight noded, elements shapes are hexahedral and interpolation functions as trilinear were implemented for the wavy C.N.T.s fiber and polymer matrix Lanczos eigen solver method is used for this analysis. The alignment and distribution of C.N.T.s inside the matrix is basically random but the functionalized C.N.T.s and novel fabrication technique helps in achieving aligned and well dispersion [5,6]. Thus accordingly in the present work C.N.T.s are evenly distributed inside the matrix has been considered. The modeling shown in Figure 6.2. can be done based on the wavelength and waviness ratio as given in the Figure 6.1. First of all model analysis or model dynamics is being done to know the natural Frequency, eigen values etc. this type of analysis is a linear potential analysis.

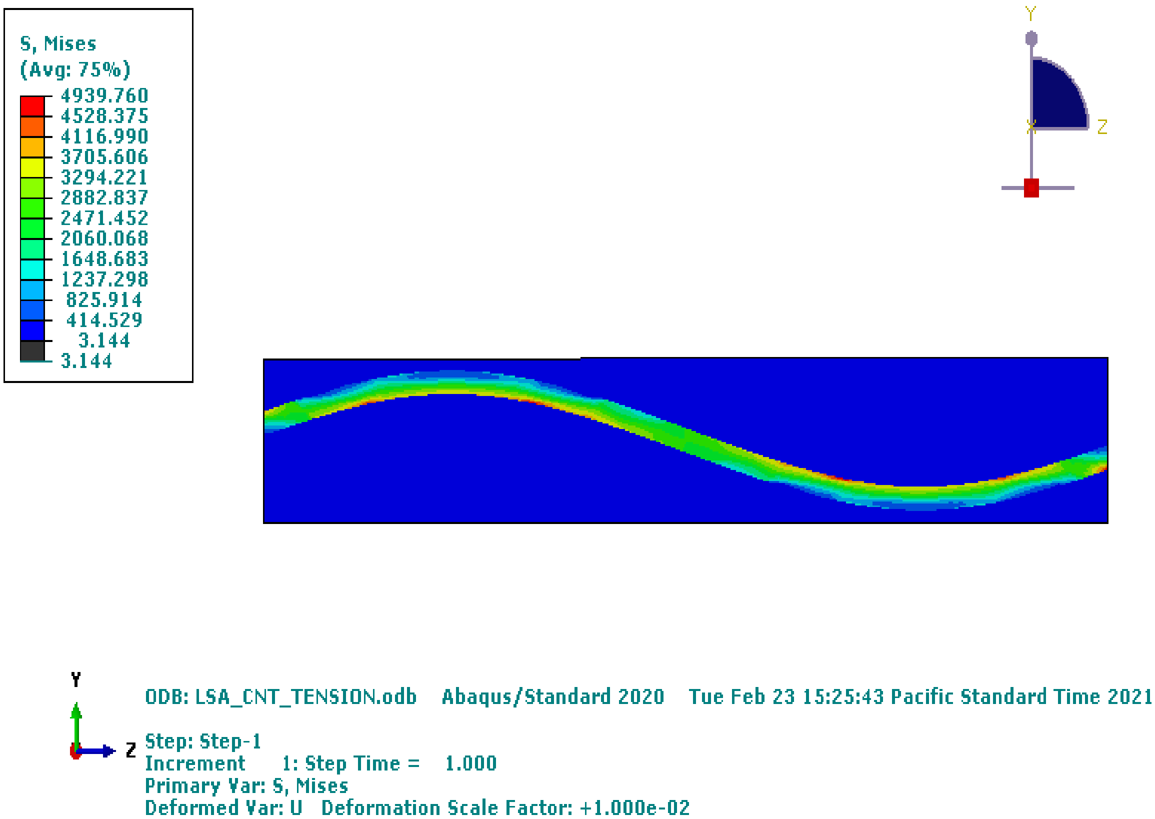


Figure 6.3. Von mises stress contour plot under load U_3 =10

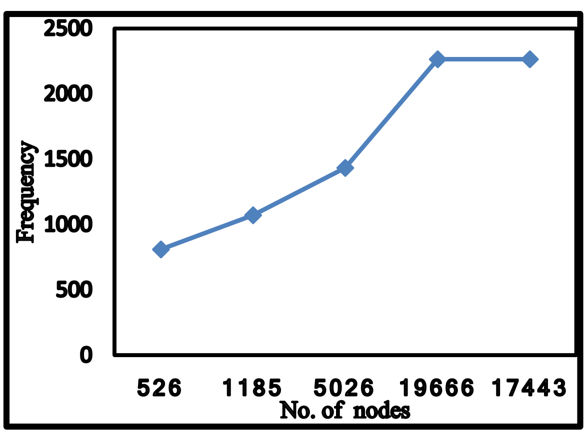
But before going for analysis the important point must be clear that is why it is important for us to understand the natural Frequency of any system body or any part. If loading frequency and natural Frequency match resonance happen and structure can fail and the classic example for resonant condition are Tacoma narrows bridge disaster.

Table 6.1. Mechanical Properties of the constituent material [184]

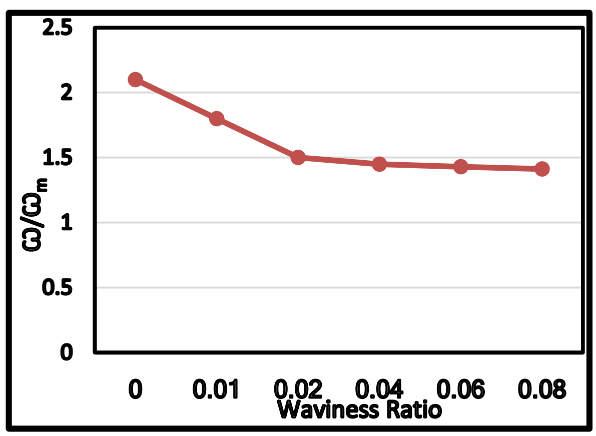
Material	Density	Modulus of elasticity	Poisson's ratio
CNT	1.6g/cm^3	1.03TPa	0.063
Matrix	1.15g/cm^3	3.8GPa	0.4

6.3 Mesh convergence study

Mesh refininement deals with the study of convergence which required an appropriate mesh refinement metric and it can be local or global. Local can be stress or displacement at a point within a structure and global can be the integral of strain energy density over all domains. The convergence study depends on the metric selection. These meshes are defined by number of nodes. So, this technique is used here to check whether the mesh refinement is affecting the results of vibration of C.N.T.s reinforced composite containing wavy C.N.T.s plus matrix and can easily be concluded from Figure 6.4 that the meshing technique is effecting the results of a F.E. analysis, here in this problem five different nodes are considered. Starting the problem with coarse mesh and move further towards finer mesh until there is convergence. Figure 6.4 shows the vibrational property is affected by the number of nodes and C.N.T.s waviness the fig. containing waviness of 0.05 that is NT 4 in Figure 6.1 shown above and volume fraction, V_f of 0.013.



(a)



(b)

Figure 6.4. (a) Effect of meshing on the Frequency (b) Fundamental Frequency as a function of nanotube waviness ratio (w=a/L)

By increasing number of nodes from 526 to 19666 there is a huge difference in the result and after 19666 there is minute difference and that difference is not remarkable. This fact insinuated that 19666 nodes is reliable to give correct results. Therefore, for the computational model there is a relationship between element size and its vibrational properties of C.N.T.s reinforced composite.

6.4 Results and discussion

The primary goal of this research is to create a system that incorporates the waviness effect into standard method. It is due to embedded nano tube has been modeled using continuum approach. This method is also applicable in general for other inclusions that contain alike geometries, by describing embedded geometry, geometric property and material property.

6.4.1 Von mises stress

Before representing the vibrational properties some observation on the stress variation under displacement load are discussed. Von mises stress contour plot in the C.N.T.s reinforced composite containing wavy C.N.T.s under the different boundary condition as XSYMM defined as symmetry about a plane X=constant that is U1 =UR2 =UR3 =0 and ENCASTRE boundary condition defined as it constraints all structural degree of freedom in the specified region applied to all nodes occupy the region that is U1 =U2 =U3 =UR1 =UR2 =UR3 =0 and displacement load that is U3 =10 is applied to get the von mises stress. Fig.5. represents the stress variation in the wavy C.N.T.s and matrix where the minimum stress is developed inside the matrix which is 3.144 MPa and maximum stress inside the C.N.T.s which is 4.94 GPa. This replies that most of the load is carried by C.N.T.s applied to the nano structure. It can be seen that straight C.N.T.s carrying more load compared wavy one the reason is that all fibers are aligned in the loading direction. It helps in prediction of yielding or fracture under the complex loading condition if applied loading exceeds materials yield strength.

6.4.2 Effect of waviness ratio

Free vibration analysis of C.N.T.s reinforced composite in its natural mode can be represented in a equation form as $M\ddot{x}+Kx=0$ where K= Stiffness matrix, M= Mass matrix and x = global D.O.F.. The natural Frequency Ꞷi can be calculated using harmonic motion and solving eigen value equation $(-M\omega i2+K)=0$ to overcome non trivial solution the given condi tion must be satisfied are $|-M\omega i2+K|=0$ solving this equation leads to eigen values, ωi2, i=1,2,3…n. Where n =size of the stiffness and mass matrices=D.O.F. of complete system. The introduced model is applied to calculate the natural Frequency of a bridge and cantilever nano composite. Even though the discrete nature of C.N.T.s, The total mass of indigenous carbon atoms divided by volume of C.N.T.s is expected to be a homogeneous mass density. Natural frequencies are influenced by the size of nano composite and boundary condition. Let us define Non- dimensionalized number for natural Frequency as the ratio between Frequency of composite (ω) and Frequency of pure matrix (ω_m). The influence of waviness on frequency variation are shown in Figure 6.7. As the waviness increasing the Frequency is going to decrease. These outcomes was expected because of decreasing influence of waviness of C.N.T.s on the modal stiffness. This is because C.N.T.s have various effects on modal stiffness, which is dependent on the arrangement and configuration of C.N.T.s in the polymer. C.N.T.s are more interested in the corresponding mode shapes with certain types of vibration, resulting in greater frequency enhancement. Mostly 3rd, 4th and 6th natural frequencies are effected by waviness of C.N.T.s. For highest value of waviness of C.N.T.s fiber it has been observed that the natural Frequency of C.N.T.s reinforce nanocomposite reaches the Frequency of neat matrix and further adding of C.N.T.s does not increase the value of Frequency. These outcomes emphasizes how waviness has a significant impact on modal frequencies, to the point where it can thwarted C.N.T.s reinforcing capability.

6.4.3 Resonance

Modeling the resonance using the calculated modal frequencies and with the help of Figure 6.2 are presented here in the following Figure 6.5, Figure 6.11 and Figure 6.14 respectively. When loading frequency and natural Frequency tend towards one than there is static response from Figure 6.11. static response, $x=kF$=0.47 when loading frequency and natural Frequency are far away from this value tending towards more than two that is towards right (x1) than $x>>x_1$ and the component is safe for the dynamic analysis and static analysis is required under this zone. Another properties are anti-resonant and defined as when the resonant condition happened so getting displacement along the loading direction and suddenly displacement will go in other direction so there is anti-resonant value =116 Hz so these properties are motivating to model this. Before doing steady state dynamic first get Frequency so first of all static analysis is being performed and understand what are the different frequency mode than start applying load and go to steady state dynamic and there are three method (i) Steady-state dynamics, Direct; (ii) Steady-state dynamics, Modal; (iii) Steady-state dynamics, Subspace where Steady-state dynamics, Modal technique is used in this study. Steady-state dynamics, Direct is computationally more expensive, more accurate than Steady-state dynamics, Modal and Steady-state dynamics, Subspace if significant damping is present in the structure. There are different damping option are there like composite damping Rayleigh damping and structural damping so here in this study 5% structural damping is used and no other external damping is used. Resonance is going to happen because the mode shapes and the applied loading deflection are same so this is the importance of mode shapes. From Figure 6.8 the resonance will happen at frequency 123 Hz and static response is 0.435 and anti-resonant Frequency is 120 Hz. Similarly, from Figure 6.11. the resonance frequency is 118 Hz and anti-resonant Frequency is 115 Hz. The resonant condition modeling without damper of multi waved C.N.T.s reinforced composite is shown in fig.16 where there is huge amplification and the value is 1.841*1014. From Figure 6.15 (a) the resonance will happen at frequency 115 Hz and static response is 0.5 and anti-resonant Frequency is 112 Hz. From Figure 6.15 (a). the bridge is modeled and the transverse load is applied to obtain the resonance frequency and the value is 3 Hz. By decreasing the waviness from 50 to 25 there is increment in natural Frequency in the 3rd mode by 68.68, 5th mode by 44.6 and 6th mode by 62.4 but in other mode there is negligible difference. If multi wave and single wave C.N.T.s are compared than single wave giving the more Frequency in the 3rd mode by 206.03, 4^{th} mode by 199.8 and 6th mode by 478.6 Hz.

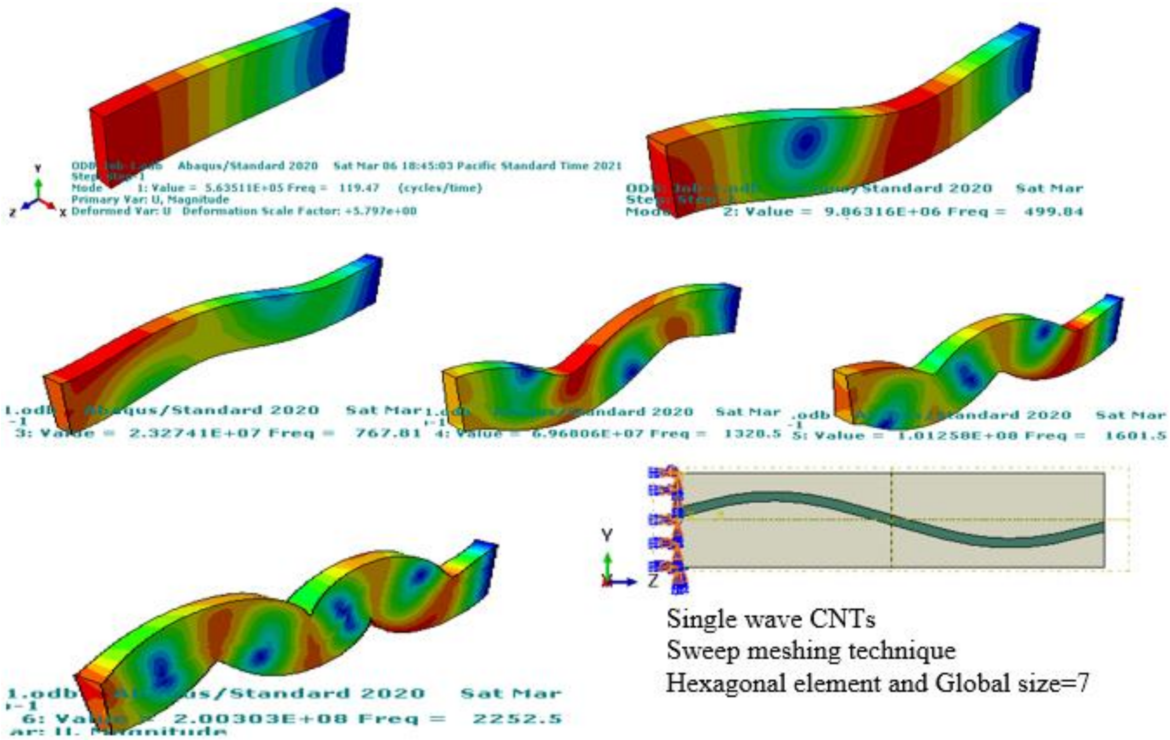
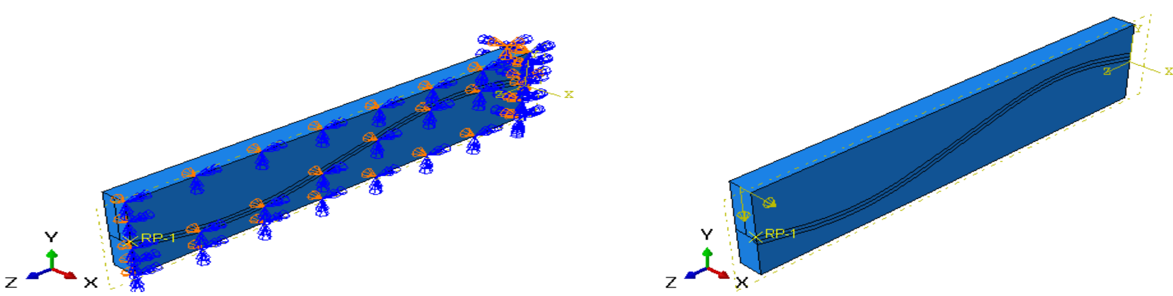


Figure 6.5. 3D plots of first six mode shapes of wavy C.N.T.s reinforce nano composite micro-beams with encastre boundary condition.



(a) (b)

Figure 6.6. (a) Encastre and axisymmetric boundary condition (b) Transverse and lateral loading.

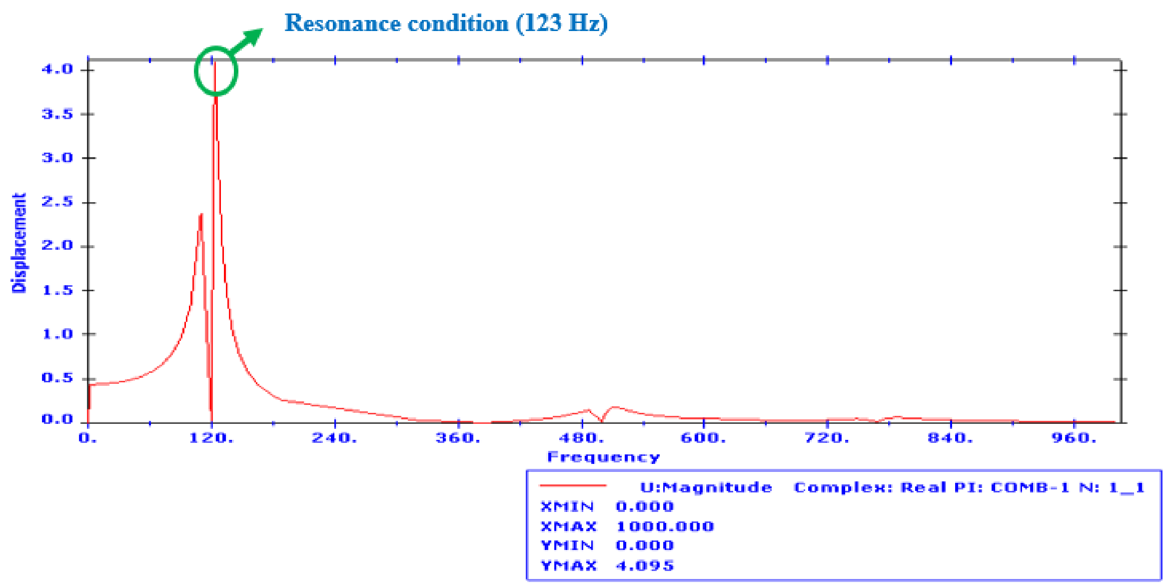


Figure 6.7. The frequency response of the structure made up of sinusoidal wave C.N.T.s inside the matrix.

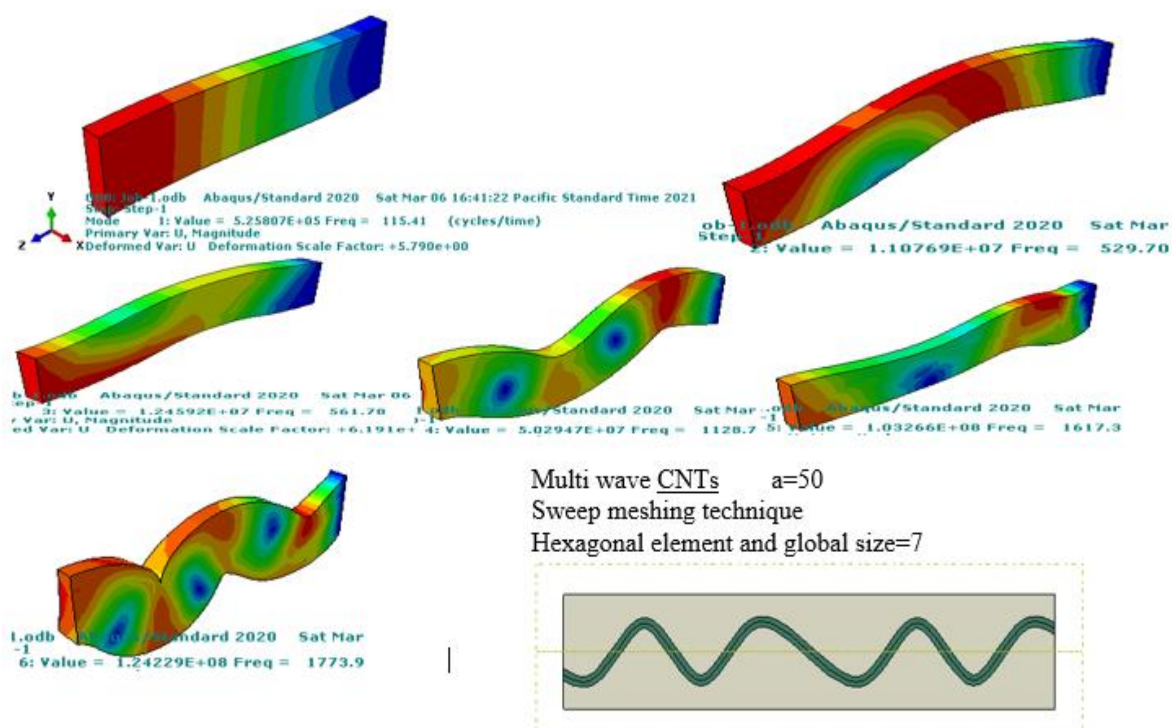
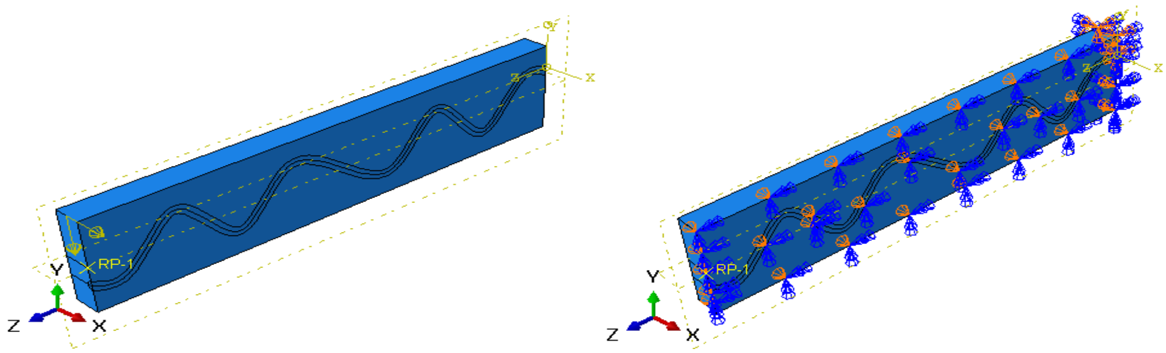


Figure 6.8. 3D plots of first six mode shapes of wavy C.N.T.s reinforce nano composite micro-beams with encastre boundary condition.



(a) (b)

Figure 6.9. (a) Transverse and lateral loading (b) Encastre and axisymmetric boundary condition.

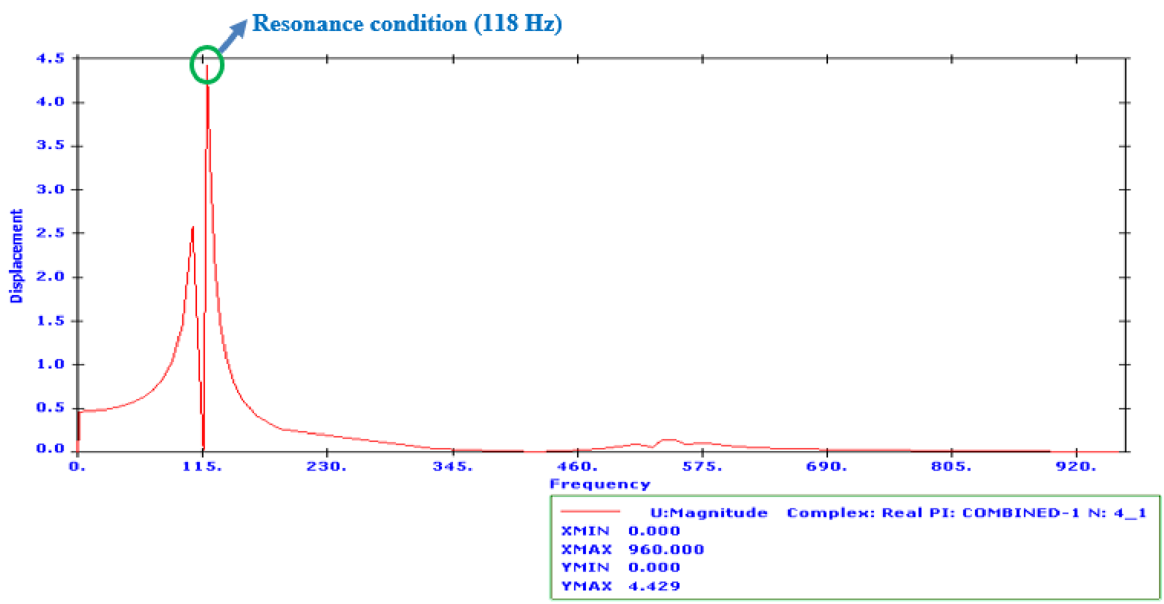


Figure 6.10. The frequency response of the structure (with damper) made up of sinusoidal wave C.N.T.s inside the matrix.

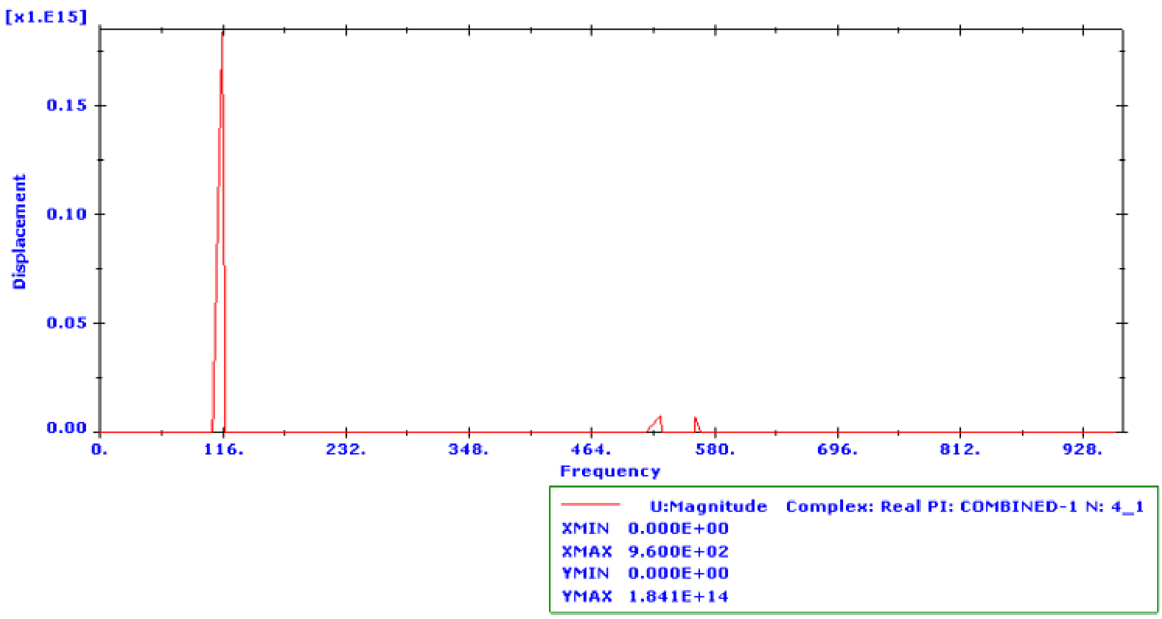


Figure 6.11. The frequency response of the structure (without damper) made up of sinusoidal wave C.N.T.s inside the matrix.

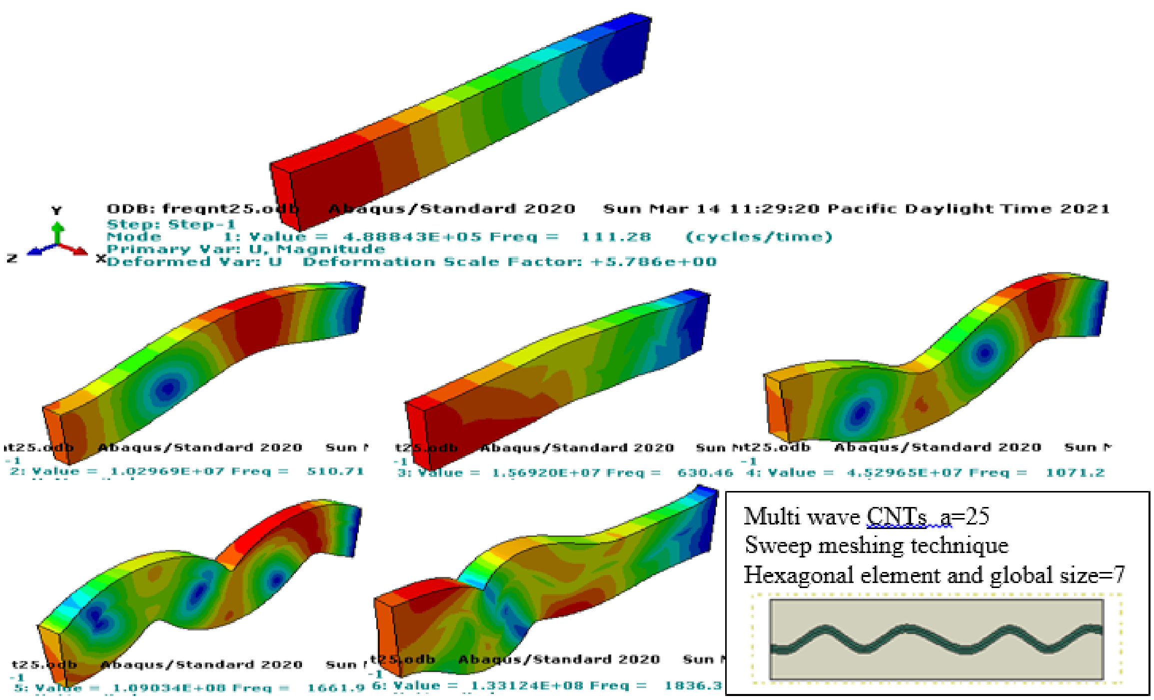


Figure 6.12. 3D plots of first six mode shapes of wavy C.N.T.s reinforce nano composite micro-beams with encastre boundary condition.

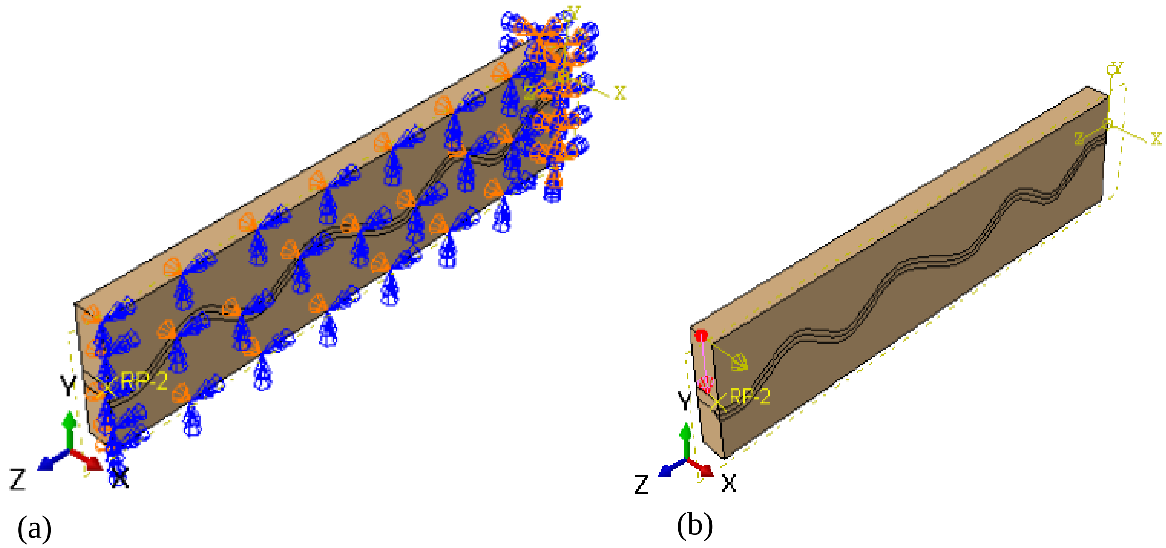


Figure 6.13. (a) Encastre and axisymmetric boundary condition (b) Transverse and lateral loading.

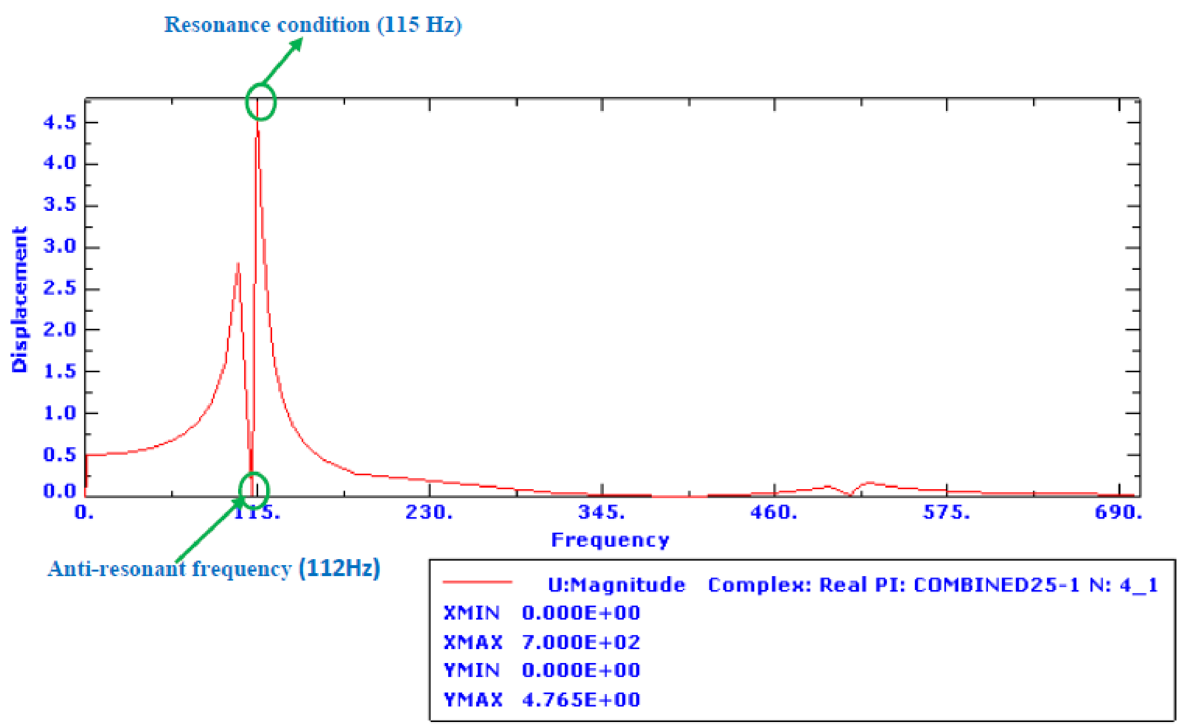
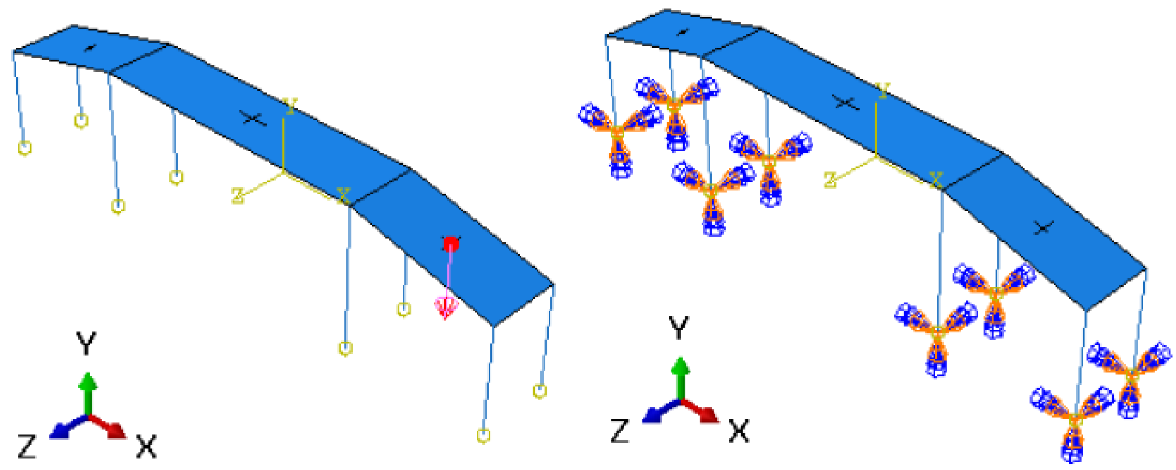


Figure 6.14. The frequency response of the structure (with damper) made up of sinusoidal wave C.N.T.s inside the matrix



(a) (b)

Figure 6.15. (a) Transverse loading (b) Encastre boundary condition

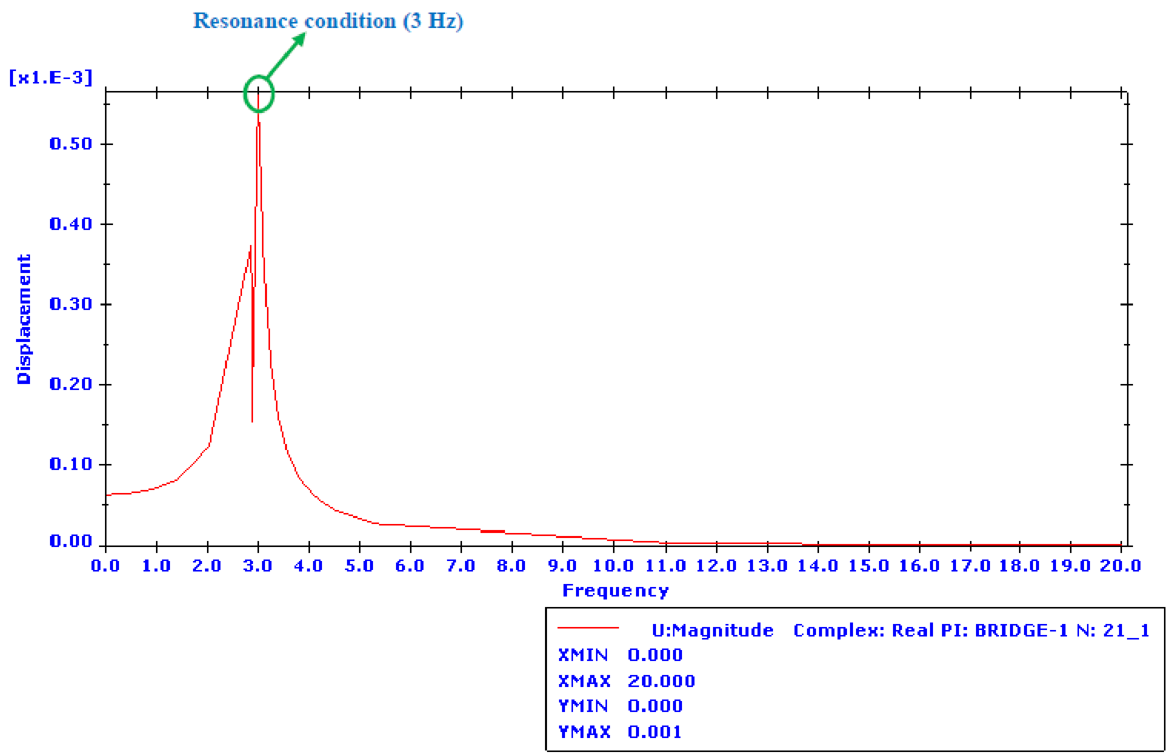


Figure 6.16. The frequency response of the Bridge made up of nano reinforced composite

6.5. Conclusion

Optimum waviness of C.N.T.s within a matrix composite micro-beam and composite bridge were obtained for endcastre and axisymmetric boundary conditions. To allocate the vibrational properties of wavy nanocomposite materials, a python code was developed. The primary objective of this investigation is to create a system that incorporates the waviness effect into standard method. It is due to embedded nano tube has been modeled using continuum approach and have been inspected as a 3D F.E. model by means of computational tool abaqus. Different node numbers and element were used to achieve the optimum mesh since the form of mesh density has a direct impact on the outcome of F.E. analysis. The effects of fibre waviness on changes in fundamental natural Frequency, resonance condition and other vibrational characteristics have been investigated. The stress variation in the wavy C.N.T.s and matrix where the minimum stress is developed inside the matrix which is 3.144MPa and maximum stresses carried by the C.N.T.s fiber which is 4.94GPa. This replies that most of the load is carried by C.N.T.s applied to the nano structure. It can be seen that straight C.N.T.s carrying more load compared wavy one the reason is that all fibers are aligned in the loading direction. It helps in prediction of yielding or fracture. In this paper modal analysis performed on wavy nanoreinforced composite and first six natural Frequency and corresponding mode shapes were extracted and than steady state dynamics were performed. For highest value of waviness of C.N.T.s fiber it has been noted that the Frequency of C.N.T.s reinforce Nano composite touches the Frequency of neat matrix and further adding of C.N.T.s does not increase the value of Frequency. Mostly 3rd, 4th and 6th natural frequencies are effected by waviness of C.N.T.s. And by increasing number of wave leads to decrement in the value of natural Frequency, mode shapes and finally resonance condition.

The main benefit of geometry used in Figure 6.5 are there is improvement in natural Frequency as 26.83% for 3rd mode, 15.04% for 4th mode and 21.25% for 6th mode. These outcomes emphasizes how waviness has a significant impact on modal frequencies, to the point where it can thwarted C.N.T.s reinforcing capability. By decreasing the waviness from 50 to 25 there is increment in natural Frequency in the 3rd mode by 68.68, 5th mode by 44.6 and 6th mode by 62.4 but in other mode there is negligible difference. If multi wave and single wave C.N.T.s are compared than single wave giving the more Frequency in the 3rd mode by 206.03, 4th mode by 199.8 and 6th mode by 478.6 Hz. There is resonance because of transverse load and there is no effect of lateral load because all mode shapes are in transverse direction as it can be observed from fig.11,15,16 and 19. If the load is applied on I-section beam than there is two resonance as due to low stiffness $\sqrt{k/m}$ in lateral direction and there is high amplification at smaller load so this is the importance of lower natural Frequency and therefore lower natural Frequency are very dangerous.