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Behaviour of Tri-Directional Advanced Composite Beam Using Finite Element Method

Pankaj Sharma[1], Ravi Kumar D[2,*], Ashish Khinchi[3]

Abstract

The present work shows the modal analysis of tri-directional advanced composite beams using the finite element method. The mechanical parameters of the beam are supposed to vary in the direction of beam length (x), width (y), and thickness (h). In this work material parameters are assumed to vary according to the exponential rule of functionally graded material. To authenticate the accuracy of the present work, the result with a particular case is compared with those obtained by previously published work (Bi-directional beam) for a reduced case. Satisfactory results have been achieved. The influence of exponent parameters and end conditions on the natural frequency of the tri-directional advanced composite beams is reported. It has been observed that increasing the exponent parameters in the width direction results in a decrease in natural frequency for all four modes. Similarly, increasing the exponent parameter in the length direction also leads to a decrease in natural frequency for all modes. Furthermore, it can be concluded that as the length-to-thickness ratio increases, the natural frequencies decrease. In this work, COMSOL Multiphysics Software is used to obtain natural frequencies. The tailored mechanical properties of tri-directional advanced composite materials make them highly advantageous for use in aircraft structures.

Keywords: Tri-directional, hybrid composite beam, natural frequencies, exponential law; vibration analysis

INTRODUCTION

Tri-directional advanced composite material beams are used mainly in aircraft structures. For example, in aircraft structures, material parameters change in two or more directions due to high temperatures [1]. so different types of multidirectional functionally graded material (FGM) models are studied for various structures. Functionally graded materials (FGMs) are the advanced form of composite material in which material properties vary in uni-direction or multi-direction [2].

In recent years, advancements in production techniques have enabled the production of advanced composite beam, which exhibits remarkable attributes such as lightweight and commendably high stiffness. The advanced composite beam is increasingly recognized in diverse engineering domains for its exceptional mechanical and thermal properties. A broad study has been done on unidirectional FGMs. Numerous studies on advanced composite beam beams have been presented [3-8]. It is also observed that some of the authors also focus on the vibration analysis of bi-directional functionally graded materials (BDFGM) beams.

Sharma et al [9]. carried out the modal behavior of bi-directional functionally graded (BDFG) beams under hygrothermal effect. Barati et al. [10].

***Author for Correspondence**
Ravi Kumar D

[1]Assistant Professor, Department of Mechanical Engineering, Rajasthan Technical University ,Kota, Rajasthan, India
[2]Research Scholar, Department of Mechanical Engineering, Rajasthan Technical University ,Kota, Rajasthan, India
[3]Technical Assistant, Department of Mechanical Engineering, Indian Institute of Technology, Jodhpur, Rajasthan, India

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examined the vibrational characteristics of BDFG nanobeams. Nguyen et al. [11] carried out the FE technique to examine the modal analysis of a BDFG beam. Modal analysis of BDFGM microbeam is examined by Trinh et al. [12]. Khaniki et al [13]. presented the harmonic analysis of BDFGM beams. Karamanli [14]. investigated the harmonic analysis of BDFGM beams under an exponential rule. Wang et al [15]. explored the modal analysis of BDFGM beams. Tang et al. [16] explored the harmonic analysis of the tri-directional functionally graded material (TDFGM) plate. Karamanli [17] also investigated the vibration analysis of tri-directional microplates. Thai et al. [18] presented the modal analysis of multidirectional FGM plates. Do et al. [19] also analyzed the material optimization of the TDFGM plate. Ahlawat and Lal [20] explored the modal analysis of a multidirectional circular plate. As observed from the published work, most of the research is related to the vibration behavior of unidirectional and BDFGM beams.

The research based on advanced composite beams is still limited. To the author's knowledge, no work is available on previously published work on the free vibration behavior of tri-directional advanced composite beams using the finite element technique (COMSOL). So, the current research focuses on studying a tri-directional advanced composite beam using the finite element method.

MODELLING OF TRI-DIRECTIONAL ADVANCED COMPOSITE BEAM

The advanced composite beam in Figure 1 has a length, width, and thickness are l, b, and h respectively. Material parameters vary according to the exponential rule [18]. Self-weight of the beam is not considered.

$$P_{\mathrm{effective}} = P_{\mathrm{lbh}} e^{\left(n_x \frac{x}{l}\right)} e^{\left(n_y \frac{y}{b}\right)} e^{\left(n_z \frac{z}{h}\right)} \quad \text{(i)}$$

where P effective is the mechanical parameters and P_{lbh} shows the reference mechanical parameters at the extreme bottom left. The n_x, n_y, and n_z are the exponent parameters in the x, y, and z directions respectively.

NUMERICAL ACCURACY

Convergence Study

The beam's parameters are as follows: length (l) = 5m, width (b) = 0.5m, and height (h) = 1m for convergence study. Figure 2. (a-d) shows the convergence study of the first four natural frequencies under different end conditions. A convergence study is performed for the exponential rule where materials having mechanical parameters E = 210GPa, ρ = 7800Kg/m^3, and υ = 0.3 respectively are used.

It is concluded from the above Figure 2 (a-d) that natural frequencies converge after 40 sampling points (normal meshing).

Validation Results

Modal analysis of the BDFGM beam under general boundary conditions is considered for validation results. The material parameters and geometric properties are taken from [21]. Table 1 compares the first dimensionless frequency of the BDFGM beam under the exponential rule. It has been concluded that the results obtained from the COMSOL software match those from [21]. The dimensionless frequency is calculated using $\Omega = \frac{\omega l^2}{h}\sqrt{\left(\frac{\rho_{lb}}{E_{lb}}\right)}$

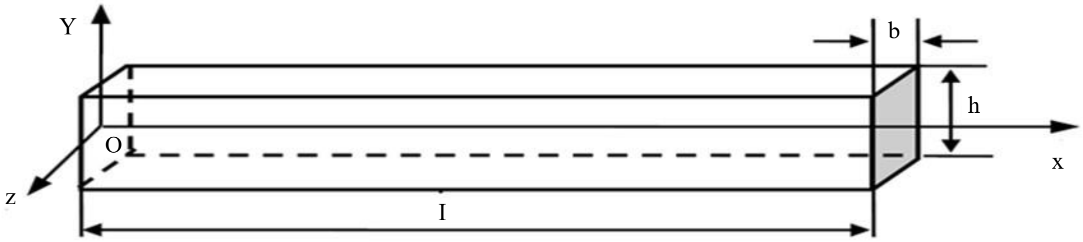

Figure 1. Geometric model of Tri-directional advanced composite beam.

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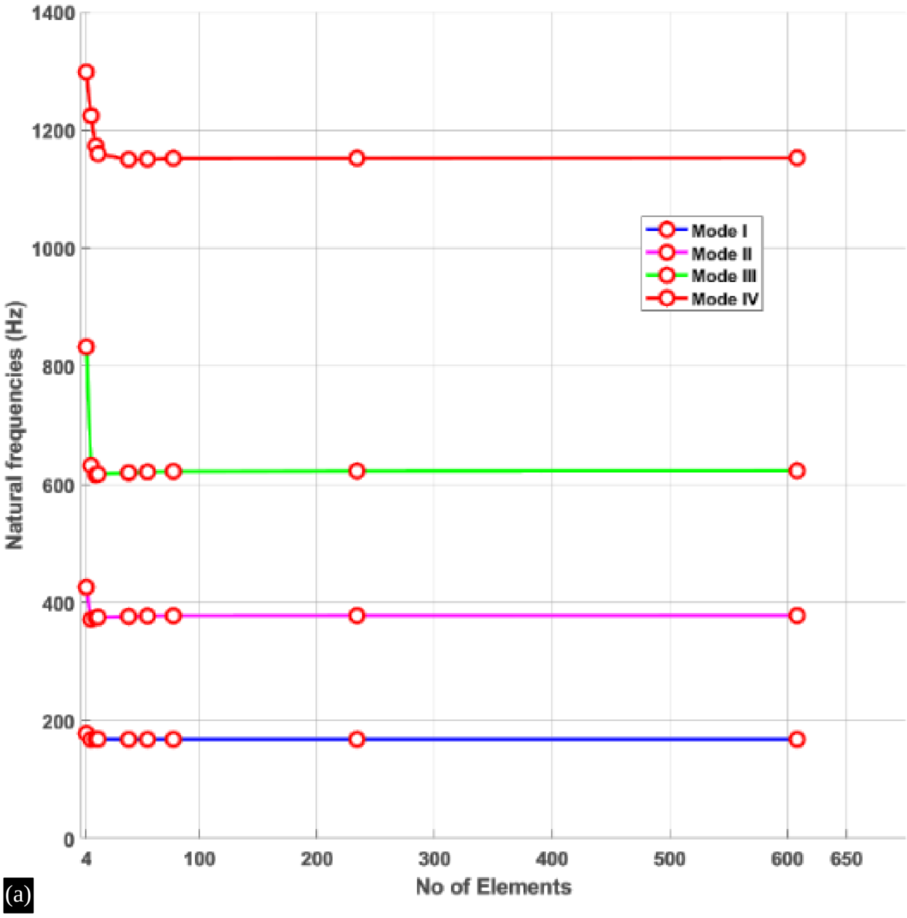
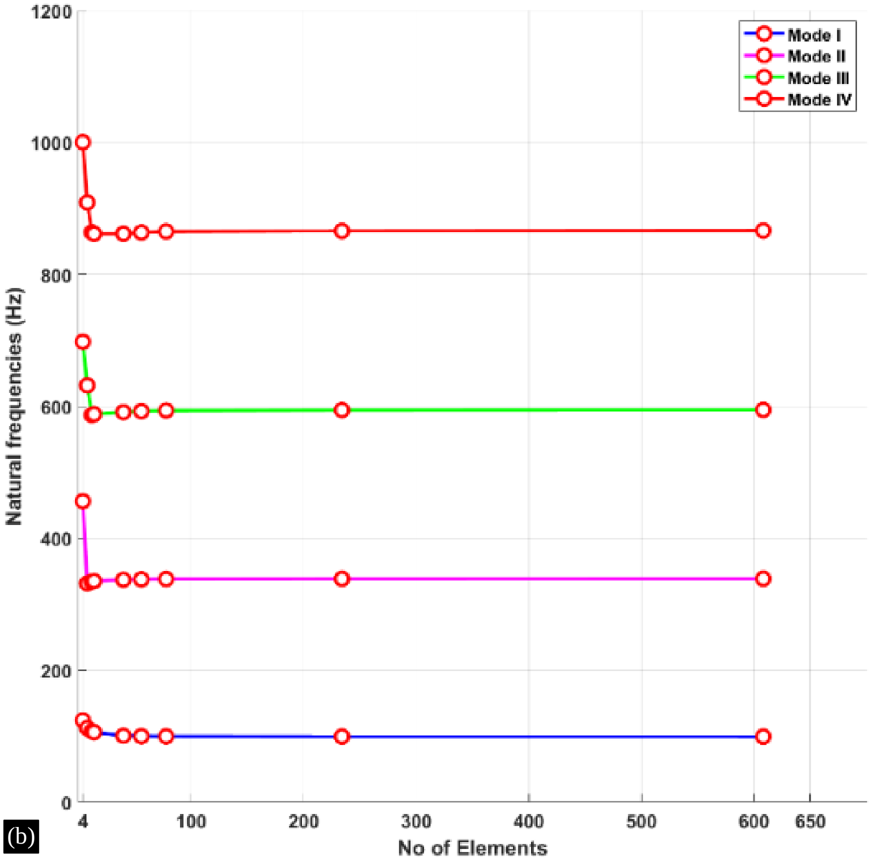


(a)



(b)

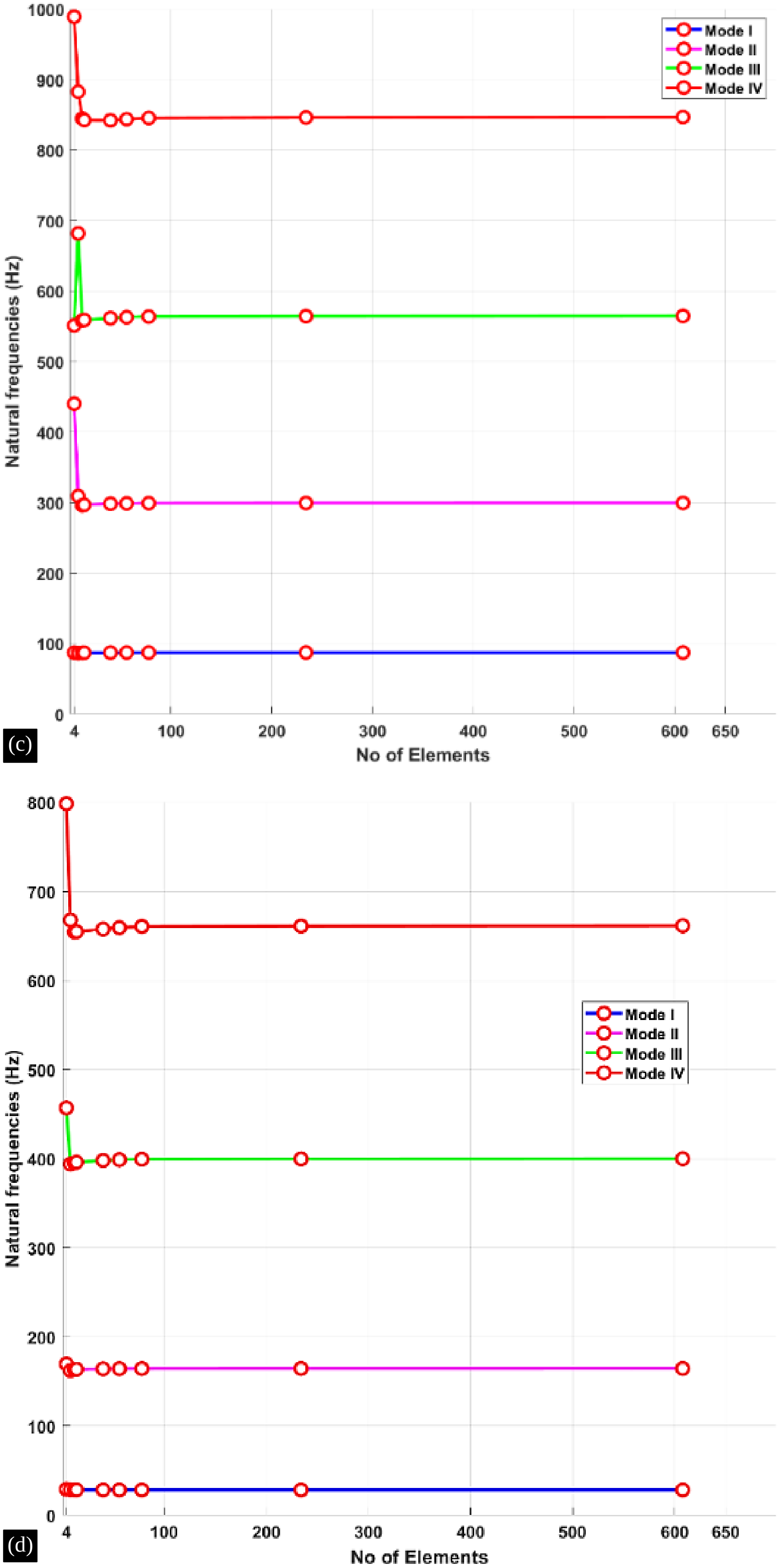


Figure 2. (a-d) Convergence behavior of the advance composite beam under exponential law (first Four modes) ($n_x = n_y = n_z = 0.5$). (a) CC; (b) CS; (c) SS; (d) CF.

Table 1. Comparison of the Dimensionless Frequency of the BDFGM Beam under the Exponential Rule.

$n_z = 0.4$							
n_x		**0**	**0.2**	**0.4**	**0.6**	**0.8**	**1**
CC	Simsek [21]	5.1806	5.1826	5.1845	5.1904	5.1962	5.206
	COMSOL	5.189	5.1744	5.1617	5.1517	5.1459	5.1465
CS	Simsek [21]	3.8622	3.7958	3.7568	3.7021	3.6455	3.5908
	COMSOL	3.8749	3.8136	3.7519	3.6897	3.6245	3.563
SS	Simsek [21]	2.6669	2.665	2.6611	2.6552	2.6455	2.6337
	COMSOL	2.6735	2.6694	2.6626	2.653	2.6466	2.6255
CF	Simsek [21]	0.9796	0.9222	0.8673	0.8154	0.7666	0.7177
	COMSOL	0.9868	0.9287	0.8733	0.8207	0.7706	0.7231

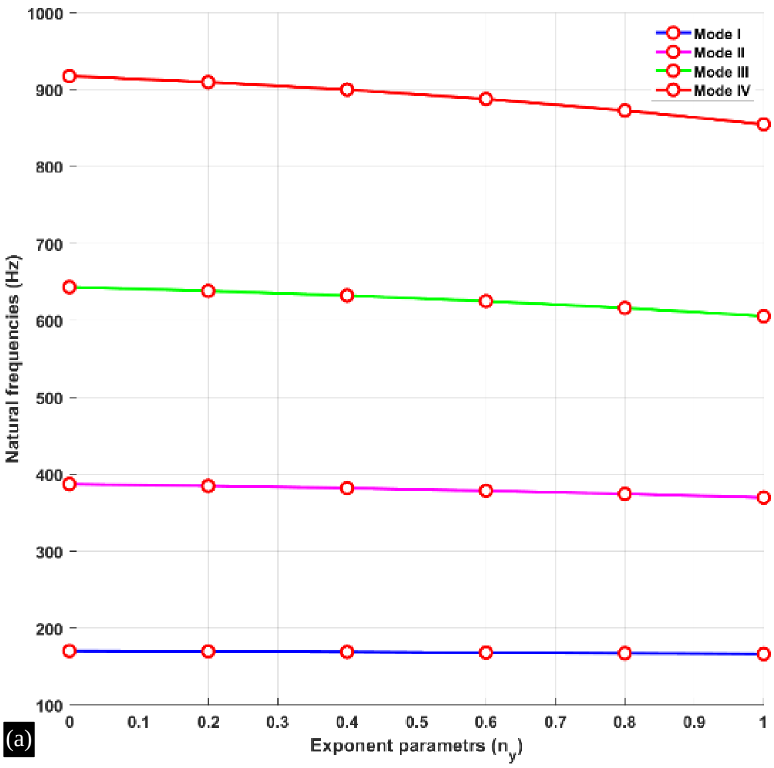
Parametric Results

The aim of this study is to examine the vibration analysis of the tri-directional advanced composite beam, taking into account the effect of the exponent parameter and various end conditions on the natural frequency of the tri-directional advanced composite beam. The beam's geometric parameters are as follows: length (l) = 5m, width (b) = 0.5m, and height (h) = 1m for this analysis. The materials having mechanical parameters E = 210GPa, ρ = 7800Kg/m^3, and υ = 0.3 respectively are used in this study. The modal analysis of the tri-directional advanced composite beam under the exponential rule is being analyzed using normal meshing. All four general end conditions are used i.e., clamped-clamped (CC), clamped-free (CF), clamped-simply supported (CS), and simply supported-simply supported (SS).

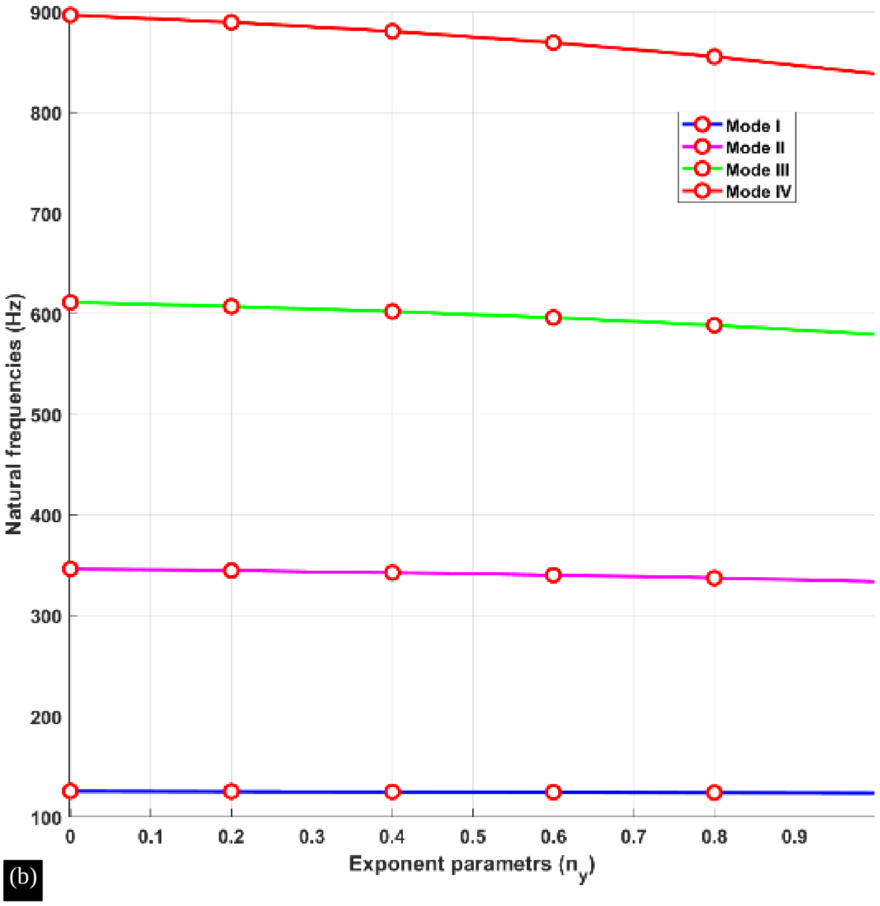
Effect of exponent parameter in y direction

In this section exponent parameter $n_x = n_z = 0.2$ is taken and n_y is varying. The exponent parameter in the y direction is taken as n_y = 0,0.2, 0.4,0.6,0.8, and 1.

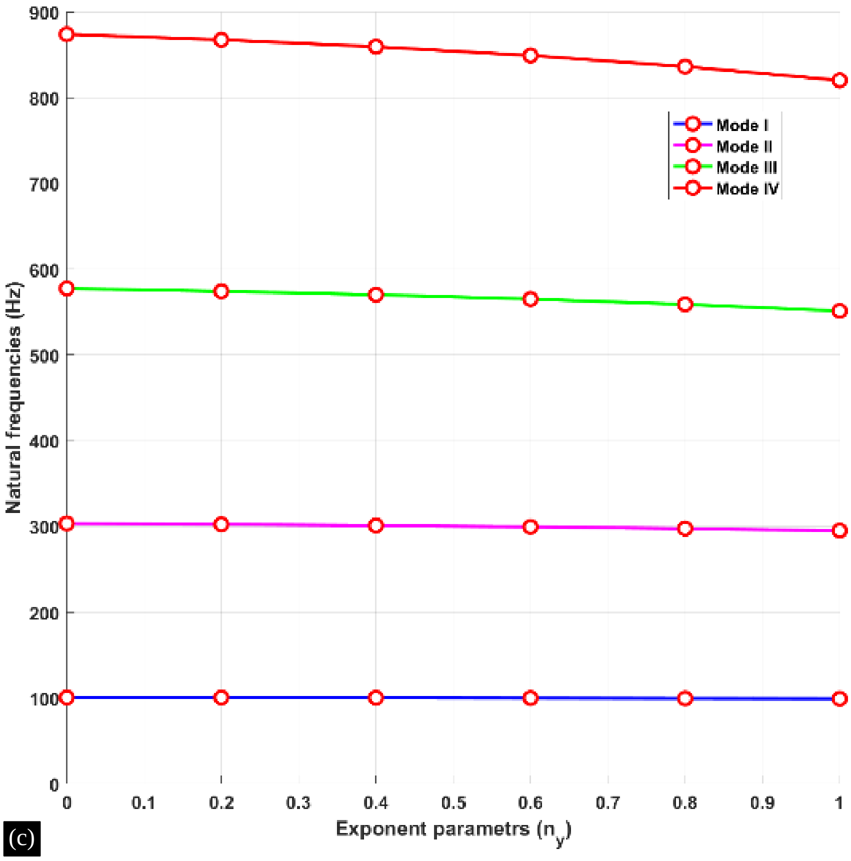
From Figure 3 (a-d), it is concluded that as the exponent parameter increases in the y direction and keeps $n_x = n_z = 0.2$ the natural frequency decreases for all four modes.



(a)


Natural frequencies (Hz)
Exponent parametrs (n_y)
Mode I
Mode II
Mode III
Mode IV

(b)


Natural frequencies (Hz)
Exponent parametrs (n_y)
Mode I
Mode II
Mode III
Mode IV

(c)

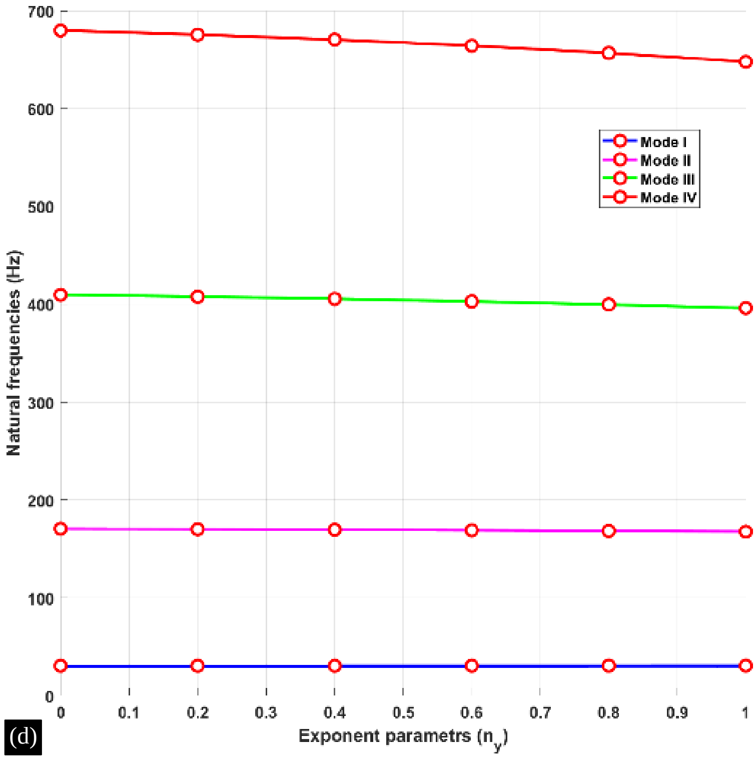
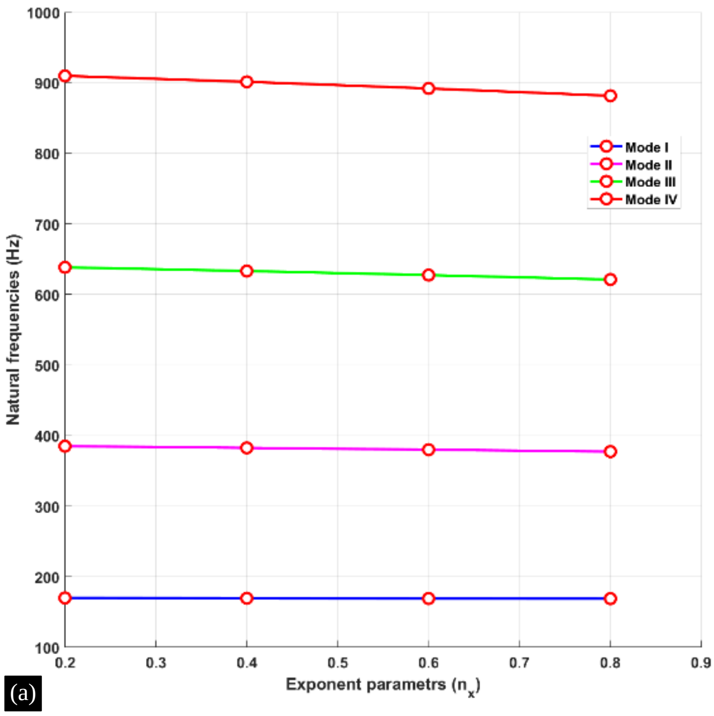


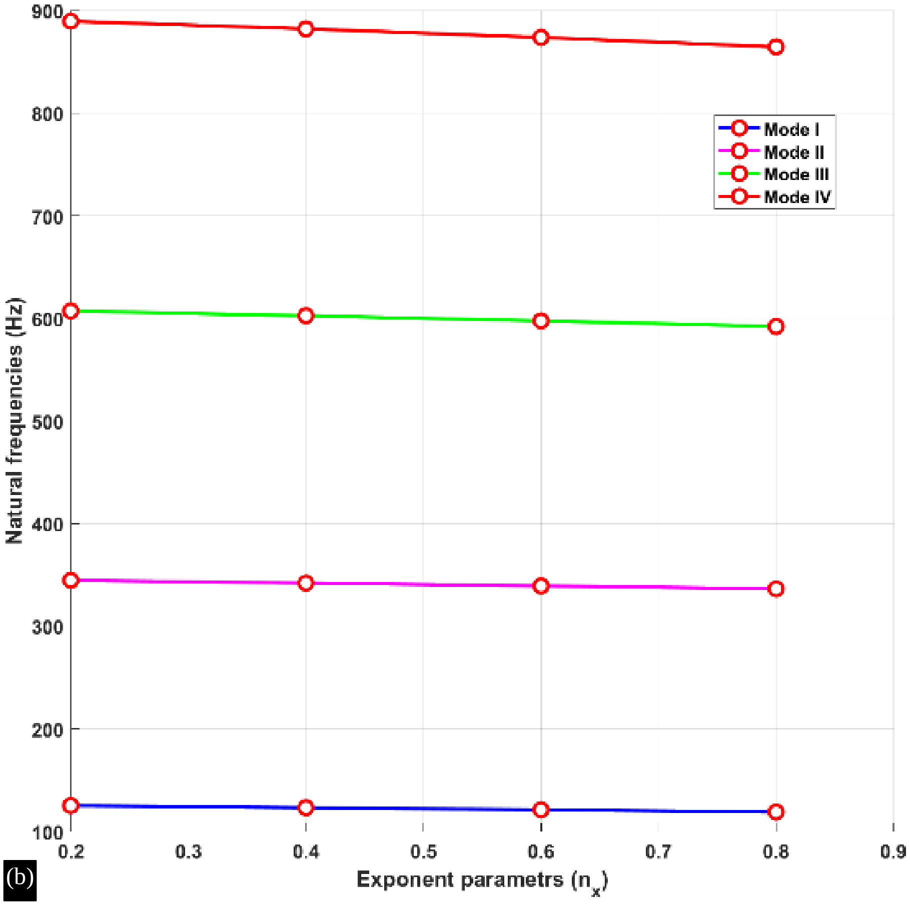
Figure 3. (a-d): Influence of exponent constant n_y on the natural frequency of advance composite beam under exponential rule. (a): CC., (b): CS., (c): SS., (d): CF.

Effect of exponent parameter in x direction

In this section exponent parameter $n_y = n_z = 0.2$ is taken and n_x is varying. The exponent parameter in the x direction is taken as $n_x = 0.2$, 0.4,0.6 and 0.8.

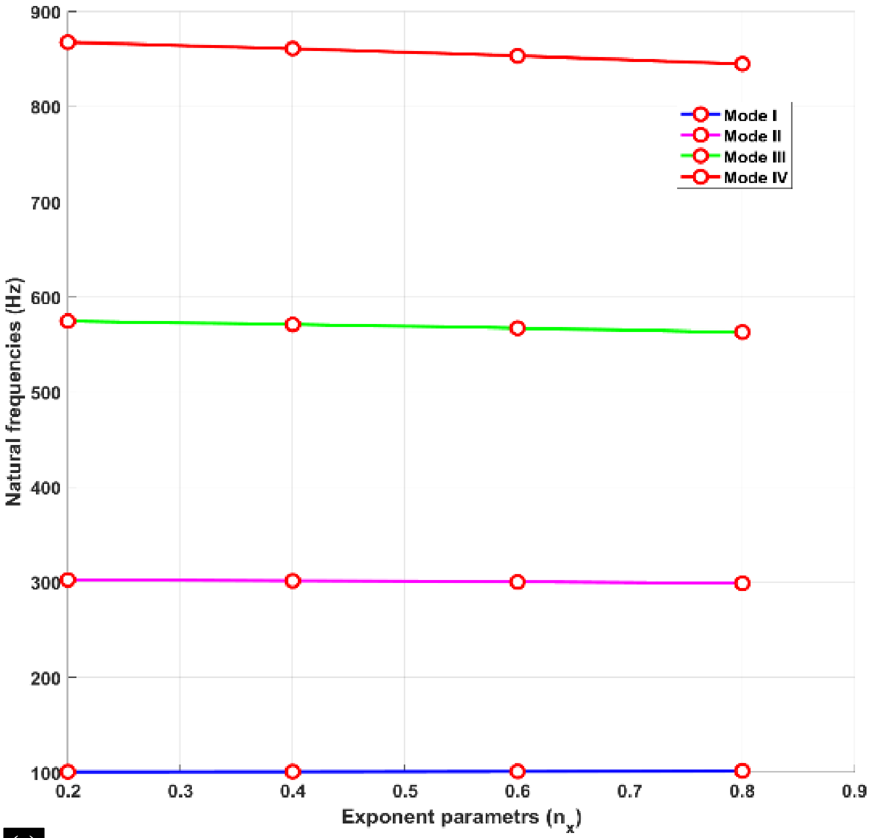
From Figure 4 (a-d), it is concluded that as the exponent parameter increases in the y direction and keeps $n_y = n_z = 0.2$ the natural frequency decreases for all four modes.





900
800
700
600
500
400
300
200
100
Natural frequencies (Hz)
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Exponent parametrs (n_x)
Mode I
Mode II
Mode III
Mode IV

(b)



900
800
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300
200
100
Natural frequencies (Hz)
0.2
0.3
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0.6
0.7
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Exponent parametrs (n_x)
Mode I
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Mode IV

(c)

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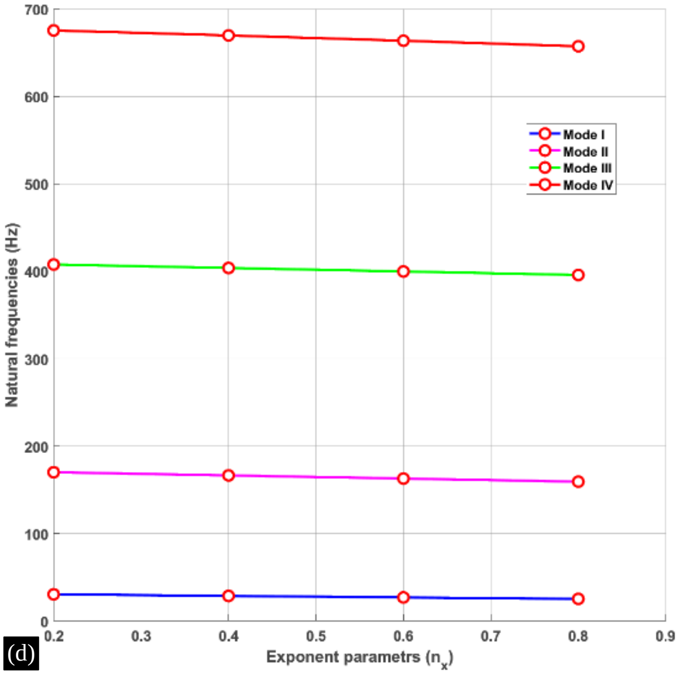

Figure 4. (a-d): Influence of exponent constant n_x on the natural frequency of advance composite beam under exponential rule. (a): CC(b): CS(c): SS(d): CF.

Effect of length-to-thickness ratio

In this section, the effect of length to thickness ratio (l/h) is compared under all general end conditions where h =1m is taken as constant and l = 5m, 10m, 15m, 20m, 25m. The material properties are the same as in parametric analysis. Exponential rule material models are used using normal meshing by keeping all exponent parameters equal to 0.5 ($n_x = n_y = n_z = 0.5$).

From Figure 5, it is observed that as increase the l/h ratio, natural frequencies decrease.

Effect of end conditions

Free vibration characteristics of the advanced composite beam under all general end conditions are compared under the exponential rule as shown in Figure 6.

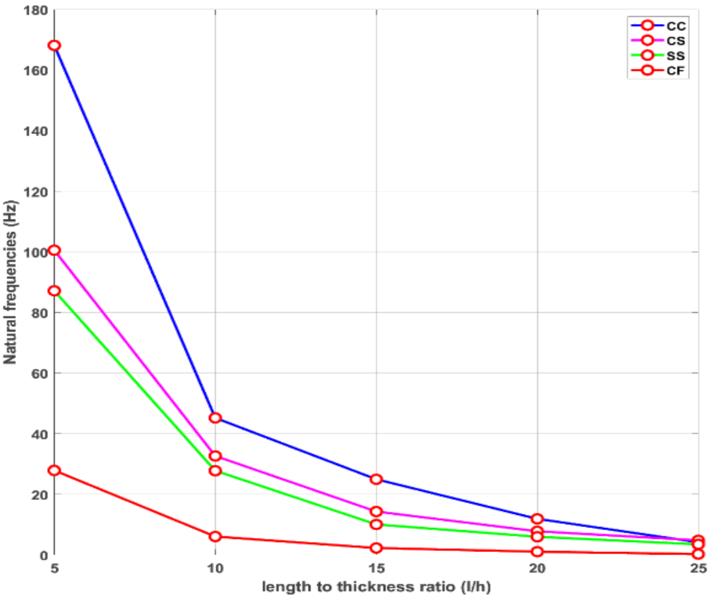

Figure 5. Effect of l/h ratio on natural frequency using exponential law.

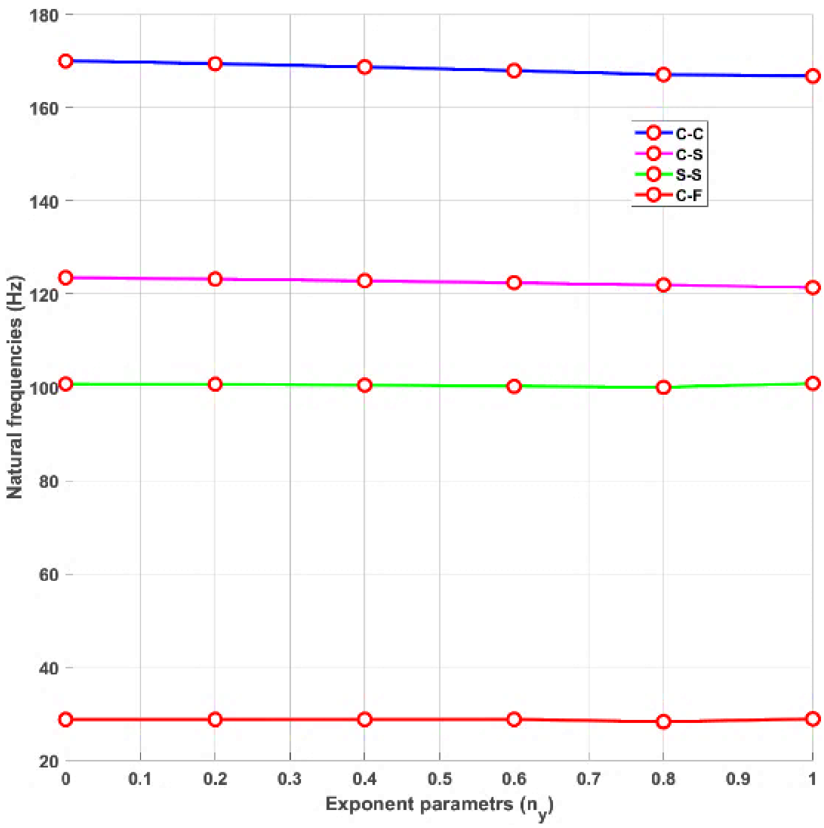

Figure 6. Comparison of boundary condition using exponential law.

CONCLUSIONS

Mechanical characteristics of tri-directional advanced composite beams with various end conditions are explored. A uniform beam is constructed with variation of mechanical parameters through length, width, and thickness direction using material models, i.e., exponential rules. Results are computed by COMSOL Multiphysics 6.2. To authenticate the accuracy of the results obtained by COMSOL software, several computed results matched with those available in the literature. The influence of the exponent constant and end conditions on the natural frequencies of the tri-directional advanced composite beam are presented.

The specific outcome from the results is as follows:

- Natural frequencies converge after 40 sampling points (normal meshing).
- Results obtained by COMSOL software close to the published results.
- As increase the exponent constants in the y direction, the frequency decreases for all four modes under the exponential rule.
- As increase the exponent constants in the x direction, the frequency decreases for all four modes under the exponential rule.
- As the l/h ratio increases the natural frequencies decrease under the exponential rule.

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