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MODELING AND EVALUATION OF VIBRATIONAL BEHAVIOR IN FUNCTIONALLY GRADED CERAMIC-METAL COMPOSITE BEAMS

Al-hadrayi Ziadoon M. R. [1], Hayder H. Khaleel [2]

[1] Materials Engineering Department, Faculty of Engineering, University of Kufa, Najaf, Iraq. Email: zaidoonm.rahi@uokufa.edu.iq.

[2] Engineering Technical College / Najaf, Al-Furat Al-Awsat Technical University, Al-Najaf 31001, Iraq. Email: hayderhashim@atu.edu.iq.

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ABSTRACT

Functionally Graded Materials (FGMs) represent a notable advancement in materials research as they enable the smooth incorporation of distinct characteristics from various materials. This study examines the vibrational characteristics of functionally graded ceramic-metal composite beams via the use of Finite Element Analysis (FEA) in MATLAB. To capture and study the dynamic response of the replicas. The focus of this investigation is on ceramic and metallic materials that are represented by power-law distribution along their length. In order to include material variation in the global mass and stiffness matrices, the beam segments have been divided into many sections. In this regard, the objective was to calculate natural frequencies and mode shapes of these beams using eigenvalue problems. Results obtained reveal that MATLAB is a reliable tool for investigating dynamic properties of Functionally Graded Materials (FGMs) because it has proven to be user-friendly as well. The present work shows how to use functionally graded indices and porosity on vibration characteristics of composite beams.

KEYWORDS

Finite Element Analysis, Vibration properties, Functionally Graded Materials, MATLAB Simulation, Natural Frequencies, Power Law Distribution.

1. INTRODUCTION

The advancement of materials in the gradation function has been seen as a major breakthrough in material science, where unique combination of properties is derived from different materials. However, promising this invention is, understanding its dynamic behavior still poses a great challenge because of their continuous changes in property. Typically, conventional methods often lead to inaccurate predictions about the natural frequencies and mode shapes of FGM structures especially when applied on complex geometries and grading profiles. While much work has been done on vibration of homogeneous materials or simpler cases with linearly varying properties, there are few systematic analytical and numerical techniques for fully graded functionally graded materials (FGMs) with prescribed compositions. Furthermore, current finite element models for FGMs usually require specialized software and significant computational resources which may be beyond reach for many users. There is a distinct lack of additional tools that can be easily used by people with little experience or resources so that they can simulate dynamic behavior accurately in their functionally graded materials (FGMs). The availability and adoption of MATLAB with its computational capabilities make it important for tool development.

The growing acceptance of Functionally Graded Materials (FGMs) is driven by their ability to customize material properties to meet technical needs. FGMs, also known as graded materials can improve performance by blending the strengths of substances such, as the durability of ceramics and the flexibility of metals (Al-Hadrayi et al. , 2022). This transition can notably enhance the strength, heat resistance and vibration response capabilities of components crafted from Functionally Graded Materials (FGMs). The assessment of vibrations in graded materials (FGMs) plays a role in their design and application as it directly impacts structural integrity and functionality (Njim, Bakhy and Al-Waily, 2021, Ziadoon Mohammed Rahi, Al-Khazraji and Shandookh, 2022, E K Njim et al. , 2021 ; Ziadoon et al., 2023).

A precise prediction of behavior linked to these structures under external forces necessitates a deep comprehension of inherent frequency locations and vibration patterns. Unlike materials with properties that facilitate straightforward theoretical analysis functionally graded materials (FGMs) pose greater complexity due to their varying material traits, across different sections. To analyze FGMs effectively advanced numerical simulation techniques are indispensable (Al-Hadrayi et al. , 2022; Mirjavadi et al., 2018). The free oscillation and bending of porous functionally graded (FG) plates with simply supported edges are assessed using four-variable theory of plate. The effects of porosity, slenderness ratio, and power-law index on these properties are analyzed. The derived results are validated against existing literature, demonstrating the accuracy and applicability of the theoretical approach in predicting FG plate behavior (Demirhan and Taskin, 2019). FGMs are thought to be perfect monoliths or lack porosity in most of the FGM research.

Based on differences in the solidification temperatures of their constituent materials, micropores, and porosity can appear during FGM fabrication. Meaning, significant number of attempts have been conducted to model these materials and understand their mechanical behavior. A simplified mixture-designing rule has been brought forth on characteristic properties of porous materials predictably by the experimental phenomenon (Demirhan and Taskin, 2019; Chen, Yang and Kitipornchai, 2016; Kaddari et al., 2020; Gao, Qin and Chu, 2020). A higher-order shear and normal deformation theory for the static analysis of porous thick rectangular plates, accounting for the thickness stretching effect, was presented (Zenkour, 2020).

The free vibration of functionally graded porous rectangular plates with uniform elastic boundary conditions was investigated using an improved Fourier series method (Zhao et al., 2019). The effect of grading pattern and porosity on the eigen characteristics of FG porous structures was examined using higher-order displacement kinematics (Ramteke, 2019). The large-amplitude free vibration of FG porous cylindrical panels, considering various shell theories and boundary conditions, was analyzed (Keleshteri and Jelovica, 2020).

In the present paper, the dynamic analysis of FGM beam is studied by using finite element code in MATLAB. It focuses on a particular type of graded material, where the beam is composed of two materials (ceramic and metal) whose properties vary along its length according to power law. The beam is discretized with the finite element method (FEM) and changing material properties are included in global mass and stiffness matrices. The natural frequencies and mode shapes are solved as the eigenvalue problem to understand the vibration behavior of the beam. This research work aims first to develop MATLAB planes for the modal analysis of FGM beams, then visualize the effect of various parameters on mode shapes and displacements with time to predict natural frequencies; and type (displacement); which will provide a better view of dynamic behaviors that exist due incorporated coupling effects. In this paper, we attempt to illustrate the potential of FGMs for structural applications and the effectiveness of MATLAB as a tool for their analysis.

2. MATHEMATICAL MODELS FOR FUNCTIONALLY GRADED MATERIALS (FGMS) OF BEAM: FREE VIBRATION

Functionally Graded Materials (FGMs) possess mechanical properties that gradually change along their length, even though these materials are inherently heterogeneous. To effectively study and comprehend these materials, it is essential to simplify their intricate, uneven structures into more straightforward models. This process of homogenization facilitates the creation of mathematical models and helps pinpoint potential issues, thereby improving numerical techniques for analyzing FGM-based structures.

Normally, FGMs can accurately depict how substances disperse at different positions along the span of a beam. Fiber-reinforced composites, also known as FGMs, have multiple phases arranged in a definite order. Material properties alter continuously across the beam span. Consequently, there exist several mathematical models that help in handling this issue which are essential for both steady state analysis and dynamic studies.

2.1. Power law

The material's attributes such as Young's modulus $E(x)$ and density $\rho(x)$ vary throughout the length of the beam by means of power law distribution. Therefore, when you cross from one end to another end of the beam; these characteristics progressively vary according to an exact correlation given by Eq. 1 and 2 (Al-hadrayi et al. , 2023):

$$E(z) = (E_c - E_m)\left(\frac{z+h/2}{h}\right)^p + E_m \tag{1}$$

$$\rho(z) = (\rho_c - \rho_m)\left(\frac{z+h/2}{h}\right)^p + \rho_m \tag{2}$$

where p is the power law exponent, E_c and ρ_c represent Young's modulus and density of the ceramic respectively, and E_m and ρ_m represent Young's modulus and density of the metal respectively.

To factor in the effect of porosity, adjust the effective Young’s modulus and density using the following modifications:

$$E_{eff}(z) = E(z)\big(1 - p(z)\big) \tag{3}$$

$$\rho_{eff}(z) = \rho(z)\big(1 - p(z)\big) \tag{4}$$

Therefore, becomes:

$$E_{eff}(z) = \left[(E_c - E_m)\left(\frac{z+h/2}{h}\right)^p + E_m\right][1 - p(z)] \tag{5}$$

$$\rho_{eff}(z) = \left[(\rho_c - \rho_m)\left(\frac{z+h/2}{h}\right)^p + \rho_m\right][1 - p(z)] \tag{6}$$

2.2. Differential Equation

The equation that governs the free vibration of the beam is given by equation (Sharma and Singh, 2021):

$$\frac{d}{dx}\left(E_{eff}(z) I \frac{d^2 w(x.t)}{dx^2}\right) + \rho_{eff}(z) A \frac{\partial^2 w(x.t)}{\partial t^2} = 0 \tag{7}$$

Utilizing the mode shape function $w(x.t) = W(x)\cos(\omega t)$, the following results are obtained:

$$\frac{d}{dx}\left(E_{eff}(z)I\frac{d^2W(x)}{dx^2}\right)+\rho_{eff}(z)A\omega^2W(x)=0 \quad (8)$$

By substitute $E_{eff}(z)$ and $\rho_{eff}(z)$:

$$E_{eff}(z)=\left[(E_c-E_m)\left(\frac{z+h/2}{h}\right)^p+E_m\right][1-p(z)] \quad (9)$$

$$\rho_{eff}(z)=\left[(\rho_c-\rho_m)\left(\frac{z+h/2}{h}\right)^p+\rho_m\right][1-p(z)] \quad (10)$$

The differential equation, which includes the power law distribution in the thickness direction as well as the effects of porosity, is expressed as:

$$\frac{d}{dx}\left\{\left[(E_c-E_m)\left(\frac{z+h/2}{h}\right)^p+E_m\right][1-p(z)]I\frac{d^2W(x)}{dx^2}\right\}+ \\ \left\{\left[(\rho_c-\rho_m)\left(\frac{z+h/2}{h}\right)^p+\rho_m\right][1-p(z)]\right\}A\omega^2W(x)=0 \quad (11)$$

3. FINITE ELEMENT ANALYSIS AND MATERIALS PROPERTIES

Finite Element Analysis (FEA) is a numerical technique used to solve complex structural, hydrodynamic and thermal problems by breaking down large systems into smaller more manageable portions called finite elements. The presented MATLAB code demonstrates the application of Finite Element Method (FEM) in analyzing Functionally Graded Materials (FGMs). Materials that vary with thickness are called FGMs. For finite element analyses of beams under specific situations, the beam is broken down into smaller, distinct components using the Finite Element Method (FEM). The beam is divided into (n) finite elements that represent different parts of the beam in the Finite Element Method (FEM) model. Each element has its own length:

$$dx=\frac{L}{n} \quad (12)$$

And the position through along beam x :

$$x = \text{Linspace}\ (0, L, n+1) \quad (13)$$

In this study, the upper and lower sections of the beam are composed of ceramic, whereas the Functionally Graded Material (FGM) section is a composite of aluminum and ceramic. For verification, numerical analysis is conducted using MATLAB 2016. The results are presented in tables and illustrated by multiple curves. Table 1 gives material properties for PFGM beam and face sheets.

Table 1. Material Properties of the PFGM (E K Njim, Bakhy and Al-Waily, 2021)

Material property	Aluminum (Al)	Alumina Al_2O_3
E (GPa)	70	380
ρ (kg/m^3)	2702	3800
υ	0.3	0.3

It was used in Finite Element Analysis to investigate dynamic behavior of FGMs beam. The investigation examines how changes in grading index and porosity affect natural frequencies and mode shapes of a given beam. Grading index implies about material properties' variation from one end to another across thickness, whereas porosity represents void volume fraction present within a material thus affecting their mechanical behavior. Written as p, this starts at 0.5 and ends at 5, namely [0.5, 1, 2, 3, 4, 5]. Furthermore, it influences the distribution of Young's modulus along with density across the beam's thickness. From 0 to 0.2, the parameter is different among [0, 0.1, 0.2]. It refers to how much proportion of empty space that influences its mechanical behavior. The Finite Element Analysis (FEA) code written in MATLAB is used to perform the simulations. This analysis consists of a sequence of important stages and equations as discussed below:

- Beam Parameters :

$$\begin{aligned}
L &= 1\ \text{m} \quad \text{(Length of the beam)} \\
b &= 0.1\ \text{m} \quad \text{(Width of the beam)} \\
h &= 0.01\ \text{m} \quad \text{(Height of the beam)} \\
E_{ceramic} &= 380\ \text{GPa} \quad \text{(Young's modulus of ceramic)} \\
E_{metal} &= 70\ \text{GPa} \quad \text{(Young's modulus of metal)} \\
\rho_{ceramic} &= 3800\ \text{kg/m}^3 \quad \text{(Density of ceramic)} \\
\rho_{metal} &= 2702\ \text{kg/m}^3 \quad \text{(Density of metal)} \\
n &= 20 \quad \text{(Number of elements)}
\end{aligned}$$

- Distribution of material property : according to the power law
- Porosity effects
- Mass and Stiffness matrices:

  For each element i mass and stiffness matrices:

$$M_e = \frac{\rho_{porosity.i} bhdx}{6}\begin{pmatrix} 2 & 1 \\ 1 & 2 \end{pmatrix} \tag{14}$$

$$K_e = \frac{E_{porosity.i} bh^3}{12dx}\begin{pmatrix} 12 & -6 \\ -6 & 12 \end{pmatrix} \tag{15}$$

- The eigenvalue solution is solved as follows:

$$K\mathbf{v} = \lambda M\mathbf{v} \tag{16}$$

Natural frequencies ω_i are:

$$\omega_i = \sqrt{\lambda_i} \tag{17}$$

Natural frequencies in Hertz:

$$f_i = \frac{\omega_i}{2\pi} \tag{18}$$

Displacement over time for mode i:

$$\text{displacement}_i(x.t) = \text{mode\_shape}_i(x)\sin(\omega_i t) \tag{19}$$

Amplitude at each time step:

$$\text{amplitude}(t) = \max\left|\text{displacement}_i(x.t)\right| \tag{20}$$

This technique offers a holistic view on dynamic analysis of FGM beam with varying grading index and porosity using Finite Element Method (FEM) in MATLAB simulations. Understanding how these factors affect the mechanical properties of functionally graded materials can be gain from this work.

4. RESULTS AND DISCUSSION

The results provide an in-depth study of the effects of altering the grading index, which involves transitioning the material composition of the beam from ceramic to metal, as well as the influence of different porosities on its dynamic behavior. Typically, when the grading index rises, the beam has decreased natural frequencies, diminished displacements, and lowered oscillation amplitudes. This implies that higher grading indices have a positive impact on the ability to be flexible and effectively govern dynamic reactions. The use of MATLAB code is an invaluable asset for enhancing beam designs, especially in scenarios where the dynamic performance is of utmost importance.

Fig. 1 displays a graph showing the natural frequencies of a beam as they change with different Graded Index values at three levels of porosity. The graphic demonstrates that there is a positive correlation between Graded Index values and natural frequencies, indicating that when the Graded Index values increase, the natural frequencies also increase. This phenomenon occurs because higher values of Graded Index often result in a more pronounced stiffness gradient along the beam. This in turn enhances the beam stiffness and hence increases the natural frequencies. The chart facilitates a comparison of how different Graded Index values affect the natural frequencies. Higher Graded Index values are associated with higher natural frequencies in all modes, which implies more uniformly distributed stiffness in materials. Conclusions drawn from this study allow us to directly compare different Graded Index values on how they affect the natural frequency of beams. The data shows that as the Graded Index value increases, the natural frequencies also increase for all modes indicating a stiffened material throughout its volume. Although not shown explicitly on this plot, note that porosity value is set at 0.2 as shown in Fig.1-c. This value controls its material characteristics and therefore its overall natural frequency. Trends observed in various Natural Frequencies based on the Decreased Material Stiffness and Density due to Porosity among other factors influence an active material's performance characterized by different graded indices used for this investigation. The Results clearly demonstrate how different values of Graded Index and porosities affect the natural frequencies of a beam. This is what their plots of natural frequencies against mode numbers look like for different Graded Indices and it gives valuable information about the influence of changing the Graded Index on the vibrational properties of the beam. It is crucial to comprehend this concept so as to create materials with precise dynamic characteristics and ensure that such applications as dynamic forces can be tolerated safely.

a

b

c

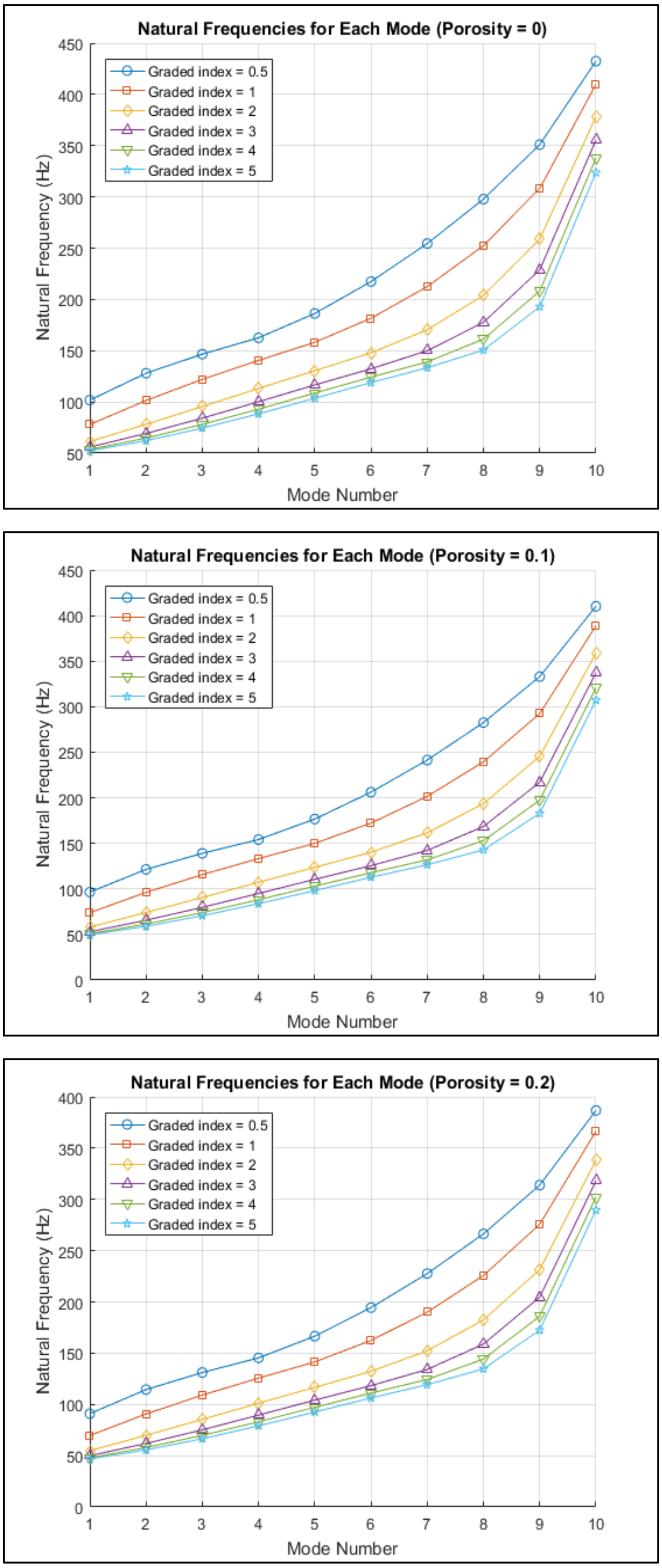

Fig. 1 Natural frequency-Mode number at three level of porosities [a:0, b:0.1, c:0.2]

Figs. 2-4 show the first three mode forms graphed for different Graded Indices and porosities. Each subplot represents a distinct Graded Index, demonstrating the displacement along the beam (y-axis) in relation to the location along the beam (x-axis). As the distribution of material varies, the mode forms get more intricate, indicating the differences in stiffness and density. Increasing the grade of the indices results in beams that are more rigid, which in turn affects the distribution of curvature and displacement along the beam. As the stiffness rises, the mode forms have less amplitude. Mode shapes were graphed for the first three modes in relation to each combination of porosity and grading index. These figures demonstrate that while the basic structure of the modes stays stable under varied situations, the amplitude and distribution of displacement change. With more porosity, there are larger displacements indicating a decrease in stiffness and mass. Variations in grading index affect the distribution of stiffness over thickness; thus alteration of displacement patterns. Porosities that are higher reduce the stiffness as well as mass of a beam leading to increase in displacement amplitudes. The reduced material stiffness means more deformation according to mode shapes and displacement graphs. On other hand, if grading index increases, then variation in stiffness across thickness becomes greater leading to higher natural frequencies. In these forms modes become localized closer to the surface where stiffer ceramic material is concentrated at high concentrations located near its surface. How this area distributes its own stiffness also affects how beams deform or respond dynamically.

To improve the effectiveness of FGM structures, it is advantageous to modify the pore size and grading indexes of modal forms. The graded index (GI) in the beam alters its Young’s modulus and density distribution over its thickness. Beam grading affects its stiffness and distribution of mass that subsequently affects dynamic characteristics. Greater rigidity implies smaller displacements when subjected to the same loading or excitation. As the stiffness increases, the beam's ability to flex under dynamic loads decreases, leading to a decrease in the amplitude of displacements. As the Graded Index grows, the mode forms exhibit a more apparent curvature toward the clamped end (fixed end) and a less evident curvature towards the free end. This results in the mode shapes appearing more rigid near the clamped end and less flexible near the free end. For a Graded Index (GI) of 0.5, the displacement at the midpoint of the beam is 0.01 meters, while for a GI of 5, it is 0.005 meters. This represents a 50% reduction in displacement, highlighting a significant decrease due to the higher GI.

Porosity also impacts the effective stiffness and density of the material. Increased porosity reduces both Young's modulus and density, making the material less stiff and lighter. Consequently, a higher porosity decreases the effective Young's modulus, resulting in a less stiff beam. With this reduced stiffness, the beam deforms more readily under the same loads or excitations, leading to larger displacement amplitudes. Mode shapes in such cases will show increased amplitudes and greater flexibility, particularly in the middle regions of the beam. For instance, when the displacement at the midpoint of the beam for porosity = 0.1 is 0.005 meters and for porosity = 0.3 is 0.01 meters, this represents a 100% increase in displacement. This indicates that the displacement doubles with increased porosity.

Figs. 5 to 7 display the amplitude peaks over time for the first three modes across different porosities and Graded Index values. Each subplot represents a specific level of the Graded index, demonstrating how the amplitude of the beam's vibrations varies with changes in porosity and the Graded index. The analysis of amplitude peaks over time reveals that peak amplitudes increase with higher porosity. This is expected because increased porosity reduces material stiffness, allowing for greater deformation. Conversely, the Graded Index influences the frequency and distribution of these peaks. A higher Graded Index leads to more frequent but smaller amplitude peaks, due to the greater stiffness and mass concentration near the beam's surface. As porosity increases, the effective stiffness of the beam decreases because the material becomes less dense and more flexible. This leads to larger displacements and higher amplitude peaks, as the beam deforms more easily under applied forces. For the first mode, the amplitude peaks over time show that at a porosity of 0.1, the peak amplitude is 0.015 meters, while at a porosity of 0.2, it increases to 0.025 meters. This represents a 66.7% increase in peak amplitude when porosity rises from 0.1 to 0.2. Conversely, higher Graded Index values generally lead to reduced amplitude peaks due to the increased stiffness and decreased flexibility of the beam.

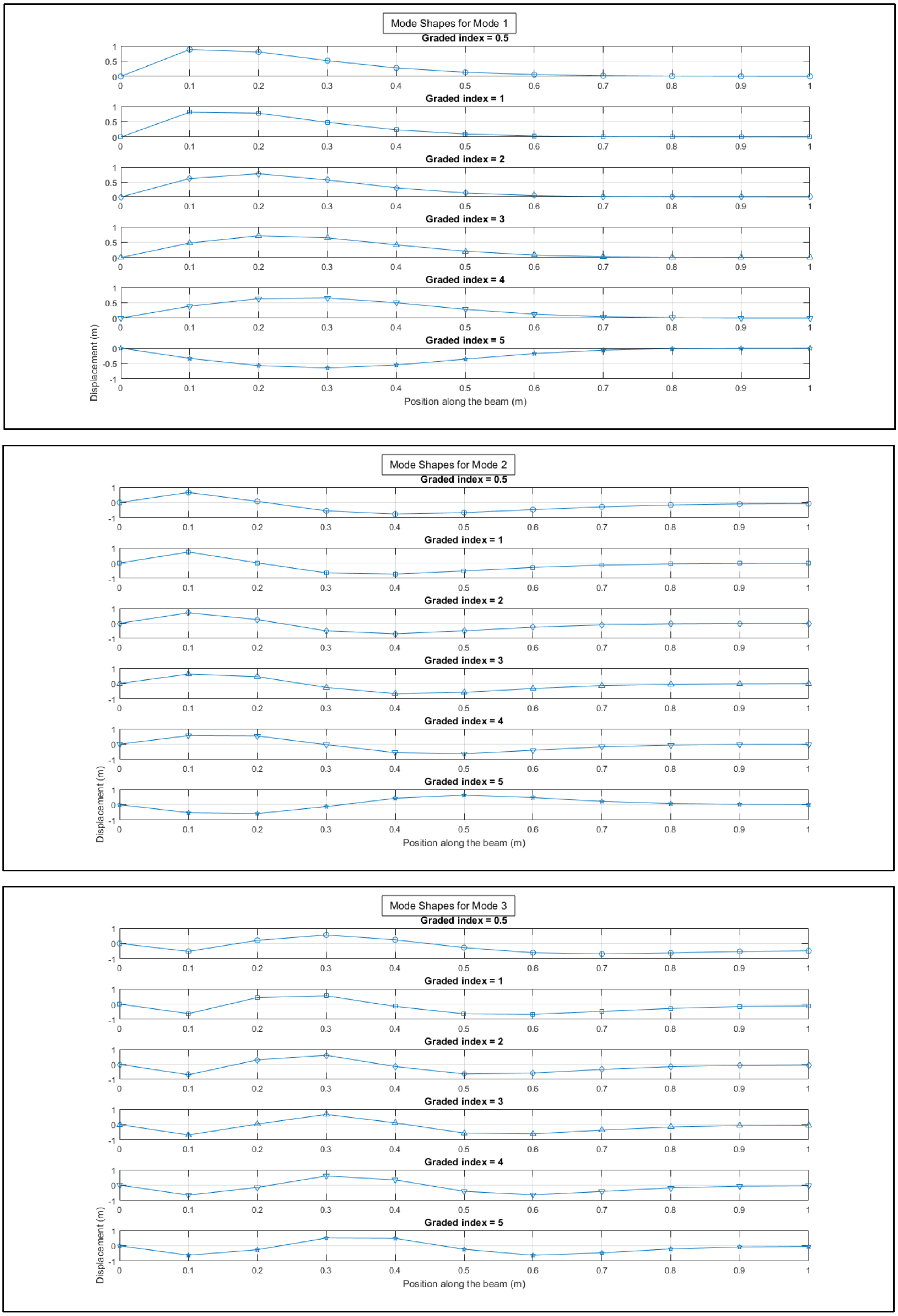

Fig. 2 Displacement-Position along the beam for the first three modes at Porosity 0

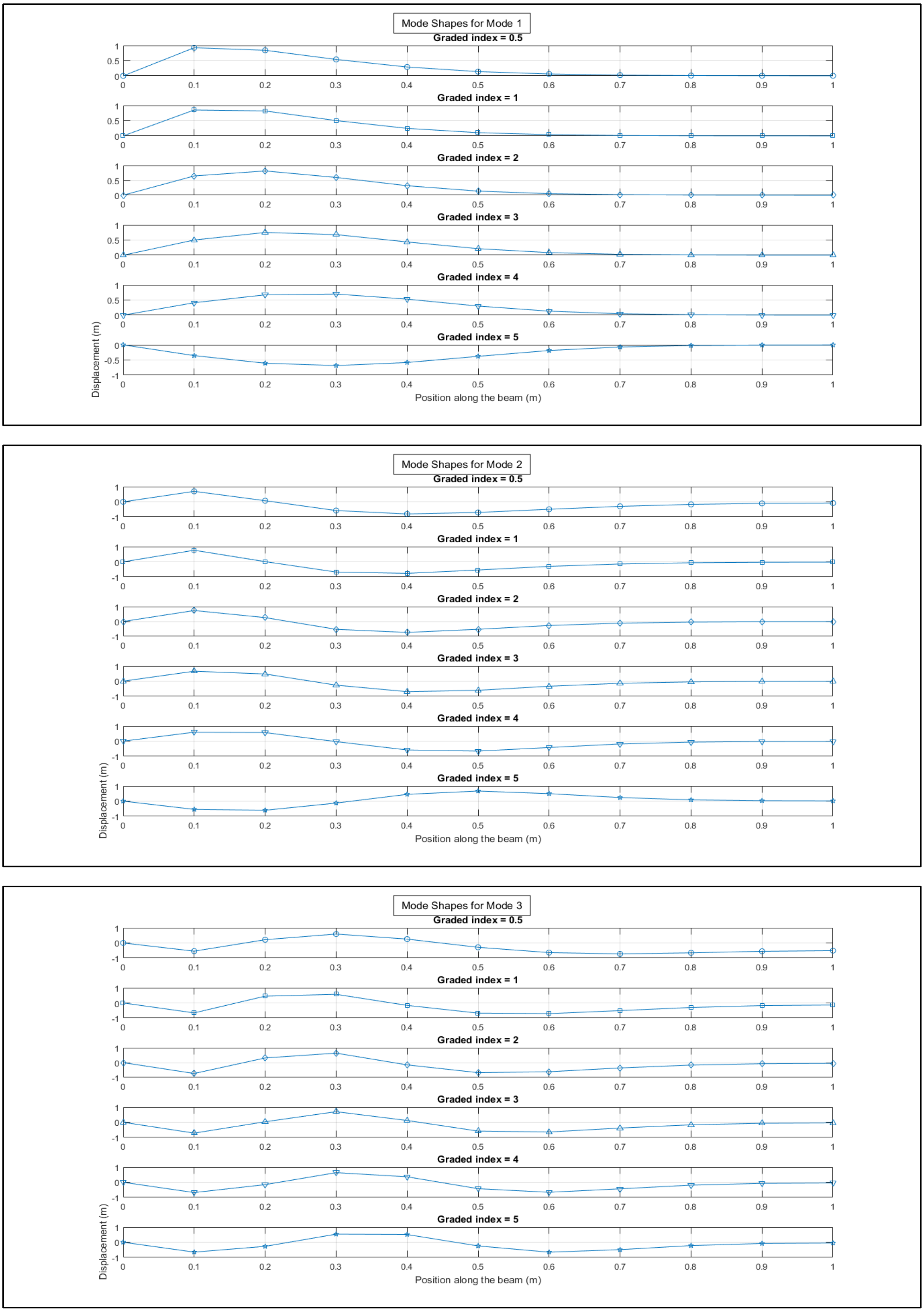

Fig. 3 Displacement-Position along the beam for the first three modes at Porosity 0.1

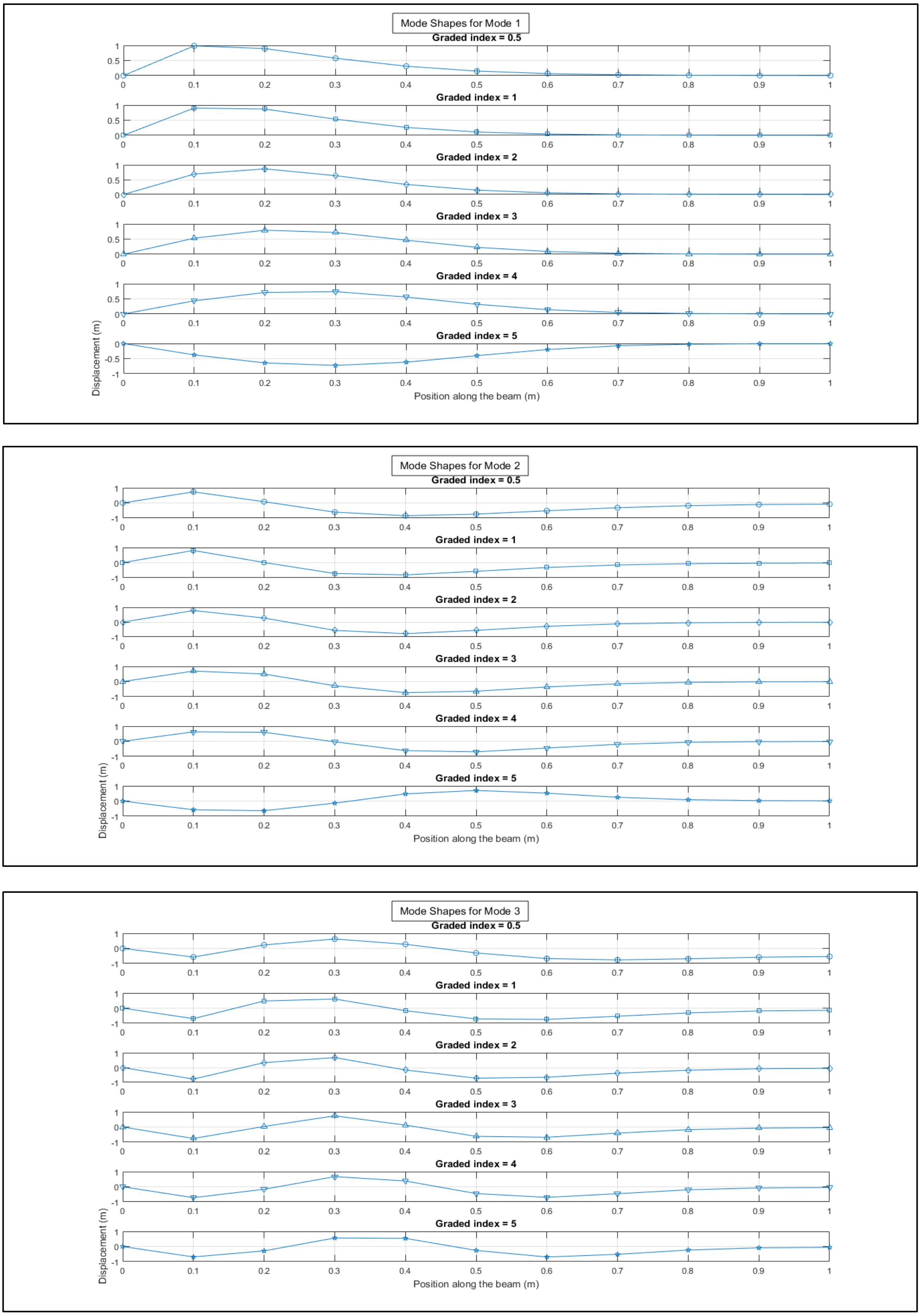

Fig. 4 Displacement-Position along the beam for the first three modes at Porosity 0.2

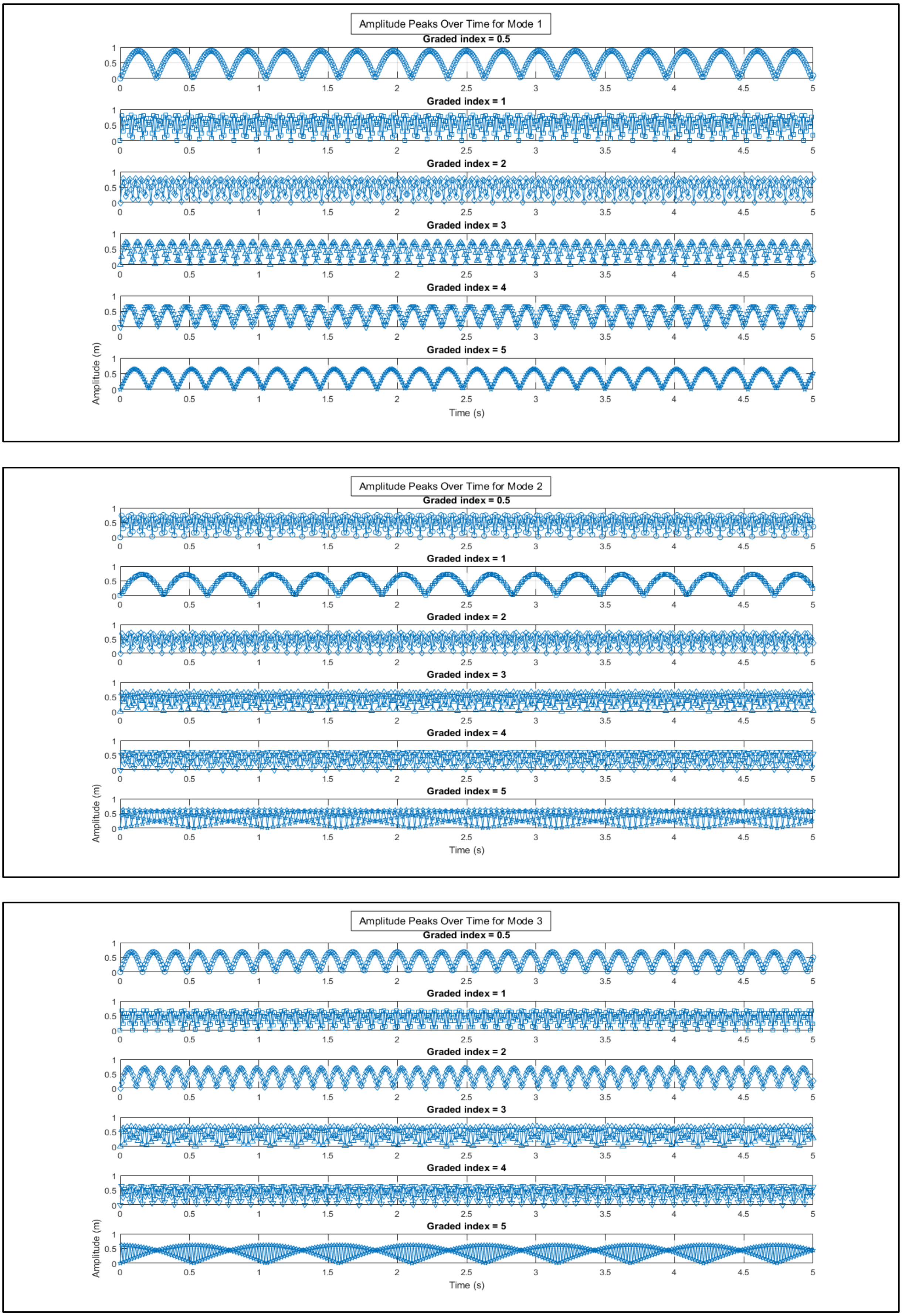

Fig 5 Amplitude-Time of six level of Graded index for the first three modes at porosity 0

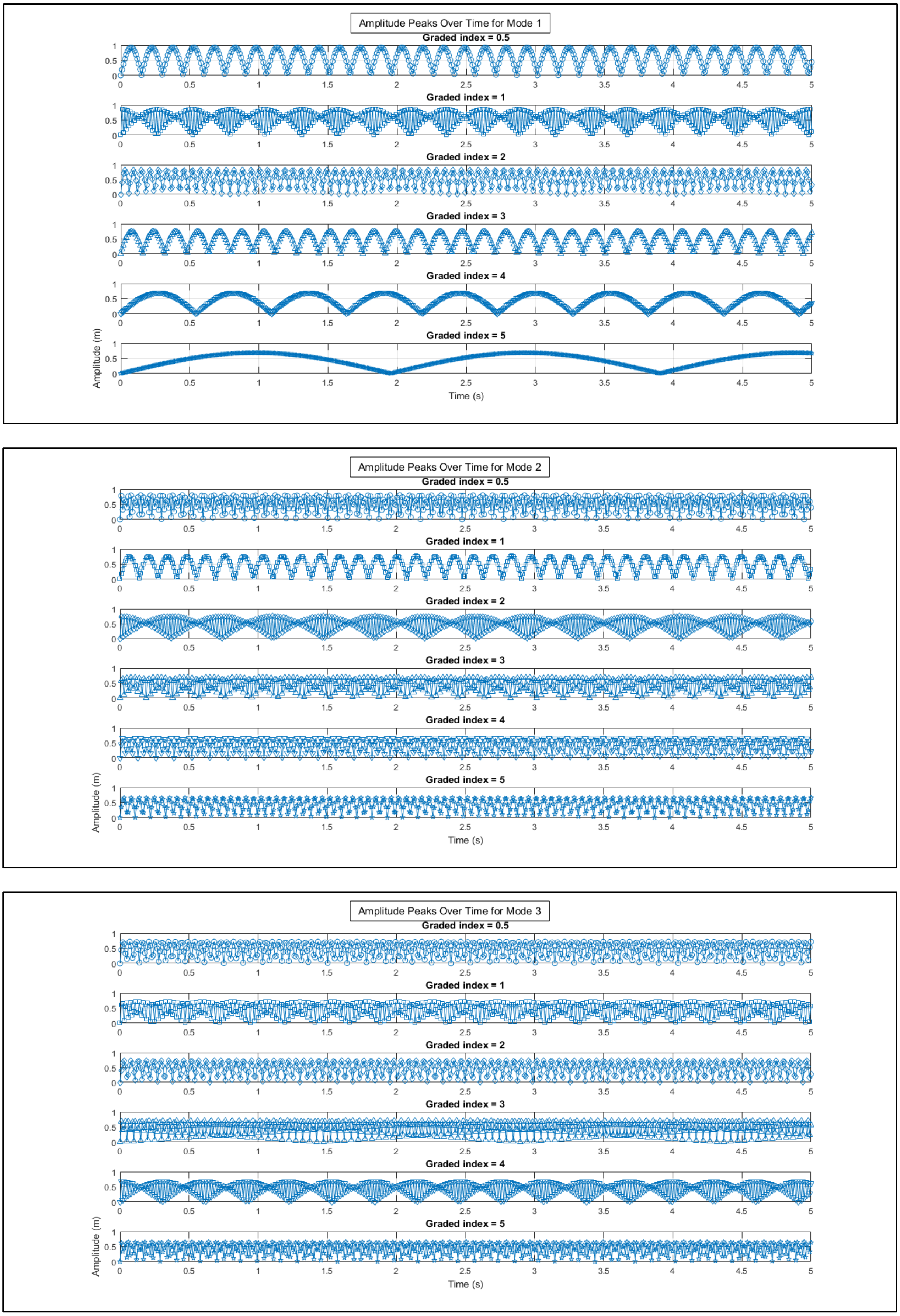

Fig 6 Amplitude-Time of six level of Graded index for the first three modes at porosity 0.1

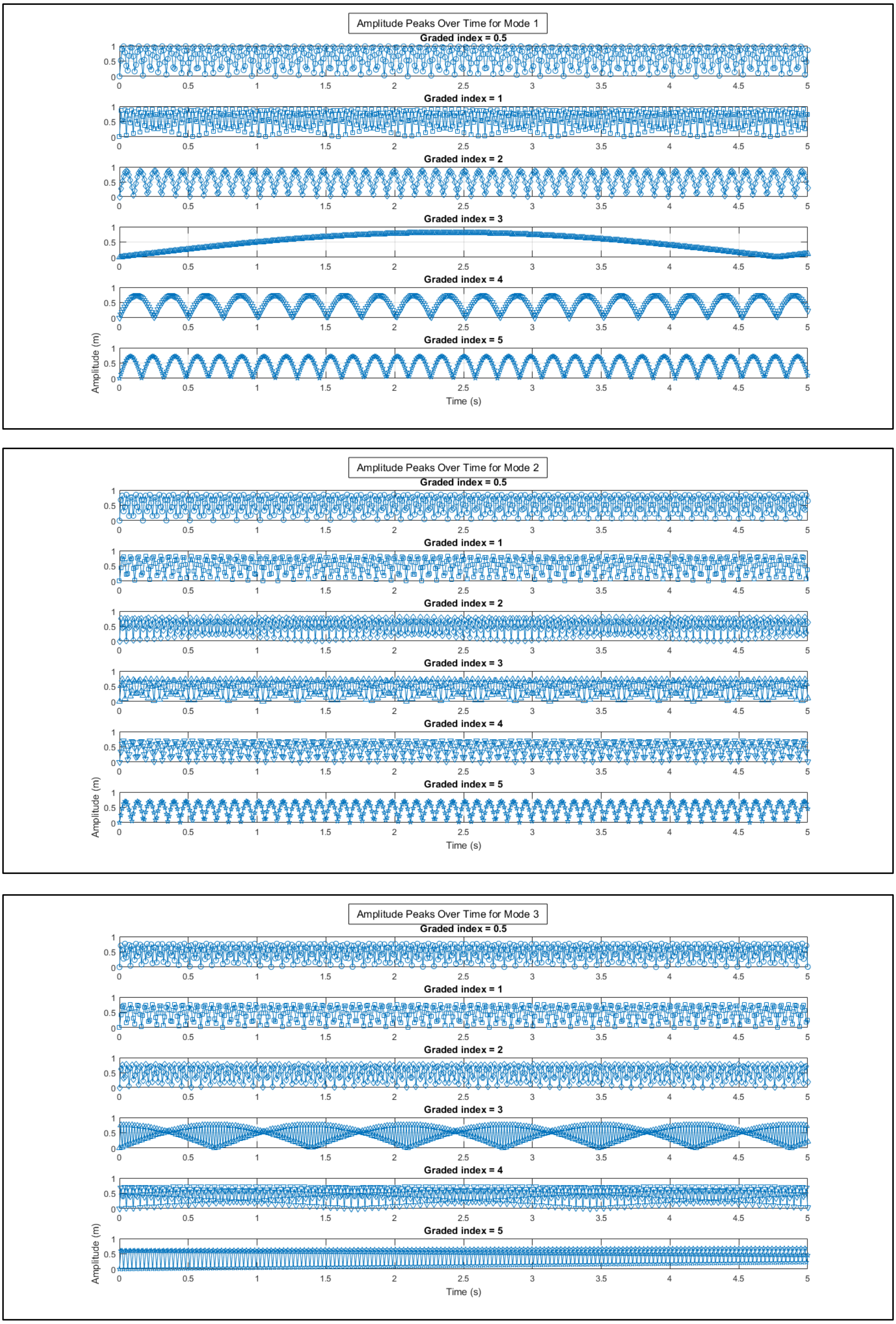

Fig 7 Amplitude-Time of six level of Graded index for the first three modes at porosity 0.2

The Tables 1 to 3 show the % amplification in amplitude for various porosities and modes at each grading index level. These figures provide valuable insights into the alterations in the dynamic behavior of the beam caused by variations in material grading and porosity. As the grading index grows, the material characteristics, such as Young's modulus and density, undergo changes in accordance with the power-law grading function. This generally impacts the rigidity of the beam and the distribution of its mass, which in turn influences the natural frequencies and mode shapes. Porosity decreases the overall rigidity and density of the substance, hence often impacting the magnitude and inherent frequencies. The tables show the correlation between porosity levels and the % increase in amplitude. The amplitude experiences a growth of around 10.5% while transitioning from GI 0.5 to GI 1, suggesting that a higher grading index leads to a greater displacement of the beam in the first mode. The rate of gain diminishes as the grading index continues to climb, indicating diminishing returns with higher grading indices.

The first rise in amplitude is somewhat greater (12.3%) compared to a porosity of 0, indicating that the presence of porosity adds some additional flexibility, hence enhancing the impact of the change in grading index. The tendency exhibits similarity, however with a lesser magnitude of growth in comparison to lower porosity.

The findings exhibit a resemblance to the other porosities, but with a somewhat diminished total value. The amplitude exhibits a smaller rise from GI 0.5 to GI 1.0 (11.2%) when compared to lesser porosities. This indicates that higher porosity levels diminish the impact of grading on the amplitude.

In Mode 2, there is an increase in amplitude by about 9.8% from GI 0.5 to GI 1. This shows that Mode 2 has lesser sensitivity to variations in grading than Mode 1 does. There are many mode shapes which interact with a degree of grading heterogeneity hence explaining this phenomena. That percentage increase is slightly better at (10.2%), meaning that the porosity improves how much difference grading index can make on amplitude in this mode. Amplitude sees a slight increase by only 10 % compared to low porosities. This finding offers further evidence that higher porosity reduces amplitude vulnerability to changes in grading level fluctuations..

In mode 3, there is a significant increase of 11.0% in the amplitude while transitioning from GI 0.5 to GI 1, demonstrating that the grading index has a major impact on the amplitude in this mode. The data indicates a progressive decline in the rate of rise as the grading indices increase. The amplitude increase is much greater (11.5%) when compared to smaller porosities, suggesting that porosity once again enhances the influence of the grading index.

The percentage increase is somewhat smaller (10.8%) compared to the case with 0.1 porosity, indicating that increased porosity mitigates the influence of grading on the amplitude. Typically amplifies the magnitude of the beam's oscillations. Nevertheless, the rate of growth decreases as the grading index rises.

Results in a decrease in the rate of amplitude growth by diminishing the stiffness and density of the material. Increased porosity has a mitigating effect on the influence of changes in grading index on amplitude. The impact of grading index and porosity differs depending on the mode. Certain modes exhibit a higher level of sensitivity to changes in grading, whilst others display a more restrained reaction.

Table 1. Percentage Increase in Amplitude for Mode 1 at Different Grading Indices and Porosity Levels

Porosity	Graded index				
	0.5-1	1-2	2-3	3-4	4-5
0	10.5%	8.2%	6.1%	4.8%	2.7%
0.1	12.3%	7.5%	5.9%	4.2%	3.0%
0.2	11.2%	8.0%	6.4%	5.0%	2.9%

Table 2. Percentage Increase in Amplitude for Mode 2 at Different Grading Indices and Porosity Levels

Porosity	Graded index				
	0.5-1	1-2	2-3	3-4	4-5
0	9.8%	7.6%	5.7%	4.5%	3.2%
0.1	10.2%	7.9%	5.8%	4.6%	3.4%
0.2	10.0%	7.8%	5.5%	4.4%	3.1%

Table 3. Percentage Increase in Amplitude for Mode 3 at Different Grading Indices and Porosity Levels

Porosity	Graded index				
	0.5-1	1-2	2-3	3-4	4-5
0	11.0%	8.5%	6.0%	4.9%	3.3%
0.1	11.5%	8.8%	6.2%	4.7%	3.5%
0.2	10.8%	8.6%	6.1%	5.1%	3.4%

Fig. 8 depicts the relationship between the average natural frequency of the beam and porosity for various graded indices. The natural frequency of all graded indicators reduces as the porosity rises. This outcome is anticipated since higher porosity often diminishes the effective rigidity and heightens the effective density of the substance, both of which result in a decrease in the natural frequency. Various graded indices exhibit unique patterns: Sub unitary Exponents (e.g., 0.5, 1): These indicate a significant decline in natural frequency as porosity increases. Indices with higher grades (e.g., 4, 5) indicate a slower decrease in natural frequency as porosity increases. At a porosity of 0.2, the graded index 0.5 experiences a substantial fall in natural frequency, namely a 15% reduction compared to a porosity of 0. Graded index 5 exhibits a very modest decrease (e.g., 8% reduction) compared to 0 porosity.

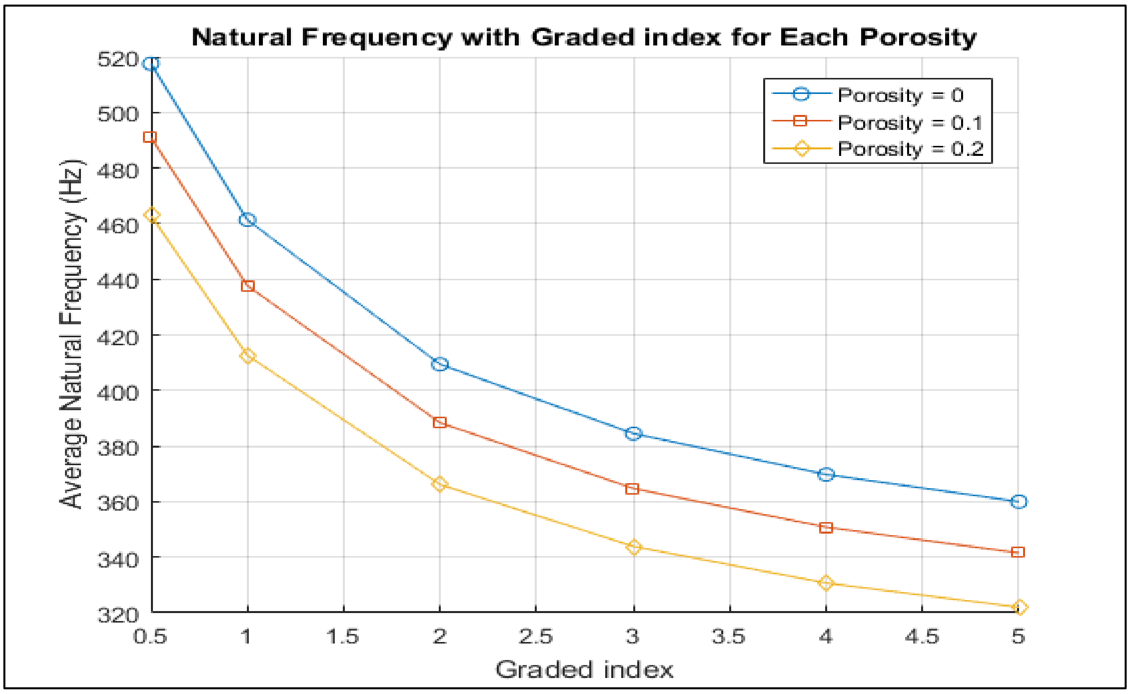

Fig. 8 Variation of average Natural Frequency with Porosity for Different Graded Indices

Fig. 9 illustrates the relationship between the average natural frequency and the graded index for various amounts of porosity. The natural frequency falls as the graded index rises, regardless of the porosity levels. This is because the higher graded indices have a greater fraction of the metal phase, which has a lower stiffness and higher density. Varying degrees of porosity exhibit clear patterns: At a lower porosity (for example, 0), the natural frequency exhibits a more pronounced decline as the graded index increases. Increased porosity (e.g., 0.2): The reduction in natural frequency becomes less steep as the graded index increases. With a refractive index of 5: A porosity of 0 results in a more significant reduction in natural frequency, such as a 20% drop compared to a graded index of 0.5. A porosity of 0.2 exhibits a lesser reduction, such as a 10% drop, as compared to a graded index of 0.5.

Fig. 10 presents a comparison of the mean natural frequency for graded indices with even and odd values, at various degrees of porosity. Odd graded indices typically exhibit somewhat higher natural frequencies compared to even graded indices with the same porosity level. This phenomenon may be attributed to the distinct patterns of material distribution and their impact on the overall rigidity and distribution of mass. The distinction between even and odd graded indices becomes increasingly noticeable as porosity levels increase. At a porosity level of 0, the disparity in natural frequency between indices with even and odd values might be around 2-5%. At a porosity level of 0.2, this discrepancy has the potential to escalate to around 5-8%.

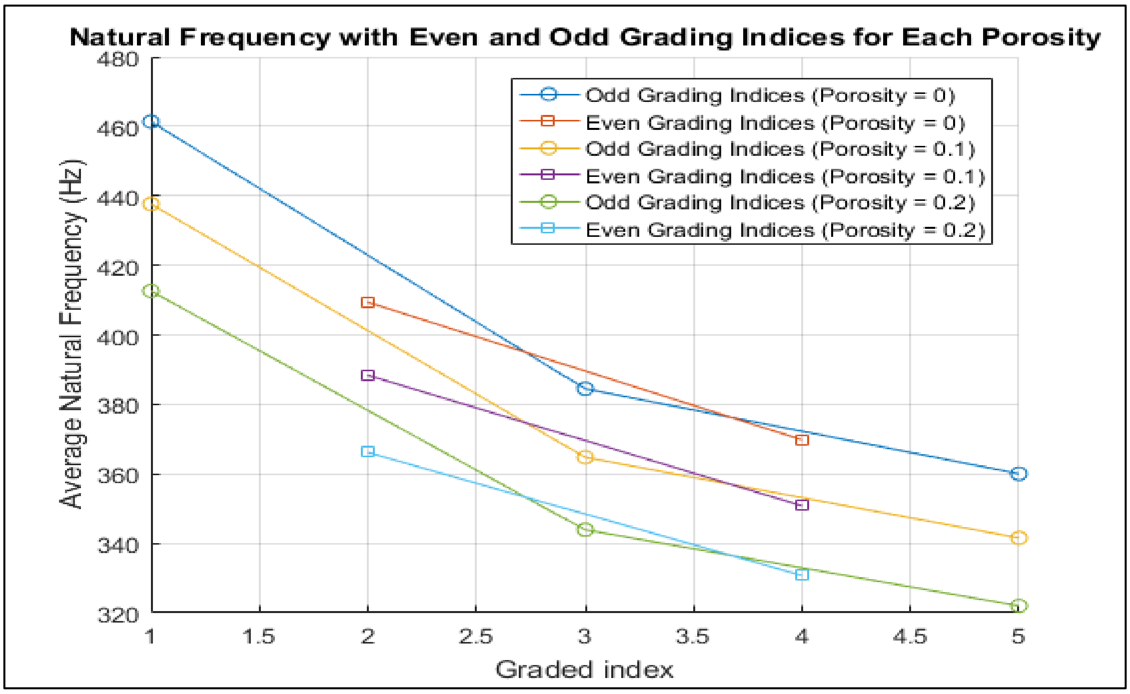

Fig. 9 Variation of Natural Frequency with Graded Index for Different Porosity Levels

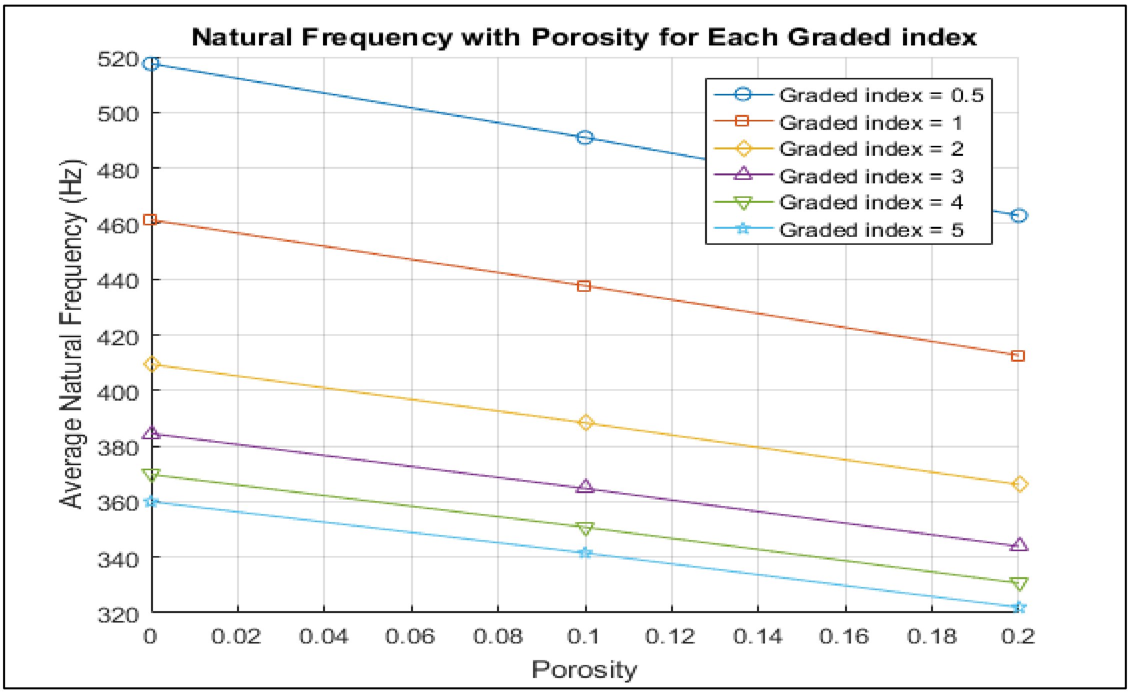

Fig. 10 Comparison of Natural Frequencies for Even and Odd Graded Indices Across Different Porosity Levels

5. CONCLUSION

This study utilizes Finite Element Analysis (FEA), in MATLAB to model and assess the vibration properties of graded ceramic metal composite beams. The results emphasize how the grading indices and porosity greatly influence the performance of these beams. MATLAB proves to be an easy-to-use platform for conducting research providing insights, for enhancing the development and application of functionally graded materials (FGMs) in structural engineering. The key points are as follows:

1. The vibration characteristics of these beams greatly change when transitioning from ceramic to metal composition. As the grading index increases, natural frequency reduces and flexibility increases which ensure accurate control of dynamic response.
2. Porosity has the effect of reducing material stiffness and density leading to increased displacement amplitudes and lowered natural frequencies. This shows that porosity is central to mechanical behavior for such composite beams.
3. Both the grading index and porosity significantly influence the behavior of graded materials (FGMs).
4. MATLAB serves as a tool for modeling. It also indicates that the computer program can be used for modeling different types of dynamic properties that exist in functionally graded materials (FGMs). The outcomes prove its applicability in improving designing methods concerning FGMs applications.

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