J Inno Sci Eng,2022, 6(1):32-45
https://doi.org/10.38088/jise.925259

Research Article

Vibration Analysis of a Sandwich Plate with Laminated Face and Porous Core Layers Resting on Elastic Foundation

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Cite this paper as:
Yuksel, Y. Z. and Akbas S. D. (2022). *Vibration Analysis of a Sandwich Plate with Laminated Face and Porous Core Layers Resting on Elastic Foundation*.Journal of Innovative Science and Engineering.6(1):32-45

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Received Date:21/04/2021
Accepted Date:22/05/2021

Abstract

In this study, free vibration responses of a sandwich plate resting on Winkler-Pasternak foundation are investigated by using the first order shear deformation plate theory. The sandwich plate is considered as laminated face and porous core layers. Material properties of laminas are considered as orthotropic and core material is porous property. The Navier procedure is used for the solution of vibration analysis. In numerical examples, vibration frequencies of the composite plate are presented and discussed for various evaluation of mode numbers, sequences of layers, foundation parameters and porosity parameters.

Keywords: Free vibration, Porosity, Elastic foundation, Laminated sandwich plate.

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1. Introduction

Sandwich composite structures consist of two face sheets and a core and have lightweight and higher strength properties. Using of sandwich composites have been increasing in many engineering fields. A typic sandwich composite have thick core layer which made of low weight, high thermal and resistance and thin face layers which made of higher strength materials. In order to obtain more low weight, the core materials iare preferred lightweight and porous properties. Porous sandwich plate have been used civil engineering applications, such as slab, bridge and decorative applications. In the appliciations of sandwich composite structures, different combination models are designed different combinations of materials such as laminated sandwich composites, functionally graded sandwich composites etc. In the open literature, dynamic investigations of sandwich plates are summarized as follows; P. Laura et al. [1] examined dynamic behaviour of non-rectangular plate embedded on Winkler type foundation. Y. Xiang et al. [2] investigated certain dynamic solution for Mindlin plate resting on Pasternak type foundation. Y. Xiang et al. [3] examined stability and dynamic behavior of thick laminates resting on foundation by using first shear deformation plate theory (FSDT). S. Parida and S.C. Mohanty [4] analyzed dynamic behavior and stability of functionally graded material (FGM) plates on elastic type foundation. T. Manoj et al. [5] examined nonlinear dynamic behaviour of thin laminas resting on Pasternak foundation. H. Shen et al. [6] investigated thermomechanical vibration behavior of laminated plates on Pasternak foundation. D. Zhou et al. [7] investigated 3D dynamic behaviour of thick plates resting on foundation. S. Hosseini-Hashemi et al. [8] performed dynamic behavior of FGM plates resting on Winkler- Pasternak foundation. Ö. Civalek and A. Yavaş [9] examined geometrically nonlinear static analysis of plates resting on elastic two parameter foundation by using discrete singular convolution method. M. Dehghan and G. Baradaran [10] investigated stability and dynamic behavior of thick plates on Pasternak type foundation by using finite element method and Differential Quadrature Method. Akgöz B. and Civalek Ö. [11] analyzed vibration of fibre reinforced plates on nonlinear foundation. P. Zhu et al. [12] investigated static and vibration responses of CNT reinforced composite plates by finite element method. R. Long et. al. [13] performed dynamic analysis of sandwich beam with core by using finite element method. T. Sharaf and A. Fam [14] presented a numerical model for sandwich plates. M. Sobhy [15] examined stability and dynamic responses of sandwich FGM plates on elastic foundations with different boundary conditions. K. Nedri et al. [16] analyzed dynamic behavior of fibre reinforced plates on elastic foundation by higher-order Theory. Mercan et al. [17] studied vibration analysis of FGM circular cylindrical shells by using discrete singular convolution method.Ş. Akbaş [18,19,20] performed wave propagation of cracked beams resting on elastic foundation under impact force. M.Ö. Yaylı [21,22,23,24] investigated vibration and buckling behaviour of nanobeam and nanotubes. L. Zhang [25] analyzed vibration of thick FGM plates reinforced by carbon nanotubes resting on elastic foundations. Ş. Akbaş [26] examined vibration and static behavior of FGM beams restingo n elastic foundation. A. Dogan [27] examined dynamic behavior of fibre reinforced plates resting on elastic foundation. M. Ö. Yaylı [28,29] studied nonlocal stability of SWCNT embedded in elastic medium. M. Avcar [30] investigated dynamic behavior of FGM beam with axial force embedded in pasternak foundation. I. Mechab et al. [31] investigated dynamic behavior of porous FGM nanoplate resting on Winkler- Pasternak foundation. Akbaş Ş. D. [32,33,34,35,36,37] investigated dynamic behavior of composite beam and plate structures with different mechanical analyses. D. Shi et al. [38] examined forced and free dynamic behavior of fibre reinforced thick plates on Pasternak foundation by FSDT. Akgöz B. and Civalek Ö. [39,40] investigated stability and vibration of micro scale structures resting on elastic foundation. H. Kadıoğlu and M. Ö. Yaylı [41] examined buckling behaviour of nano beam. A. M.

Zenkour and A. F. Radwan [42] investigated free dynamic responses of sandwich plates on elastic foundations. Yüksel Y. Z. and Akbaş Ş. D. [43] analyzed stability of fibre reinforced composite porous plate by using Navier solution. S. Dastjerdi and B. Akgöz [44] studied static and vibration behaviour of FGM nano plates under the temperature effect. B. Uzun et. al. [45] studied free vibration of FGM nano-beam by using finite element method. B. Uzun and M. Ö. Yaylı [46] investigated dynamic behavior of FGM nanobeam embedded in elastic medium. Ö. Civalek et. al. [47] investigated buckling and dynamic behaviour of nano-fibre reinforced composite plates. W. Ye et al. [48] calculated displacement of electro magnetic elastic composite plates restingon Winkler foundation. M. Ge et. al. [49] examined static behaviour of detective sandwich beam. M. Li et al. [50] investigated dynamic behaviour of FGM plates on various elastic soil model by 3D plate theory.

In this study, the effects of porosities on free vibration results of laminated composite sandwich rectangular plate with porosities resting on Winkler-Pasternak foundation investigated based on FSDT by using Navier method. Porosity effect, the uniform porosity model was considered in the laminated composite sandwich plate. Effects of the porosity ratios, the different sequences of laminas and Winkler-Pasternak foundation parameters presented and discussed in square plates.

2. Theory and Formulations

A square sandwich plate with porous core and laminated face layers resting on Winkler-Pasternak foundation is shown in figure 1 with x, y, z coordinate system. The height of laminas h_l is equal to each other and height of core is h_c.

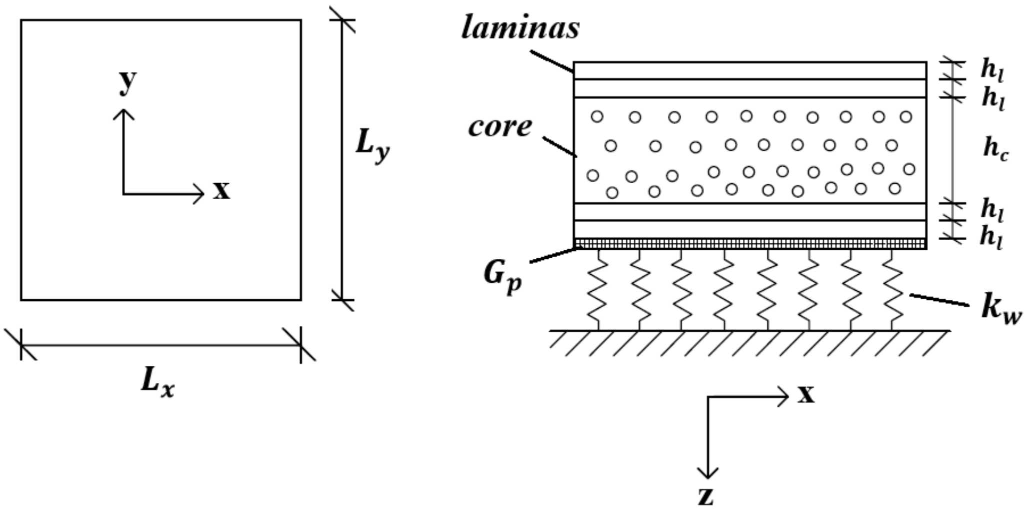


Figure 1. Laminated sandwich plate with porous core resting on Winkler-Pasternak foundation

According to FSDT, the strain components are given in terms of displacement;

$$\varepsilon_{xx} = \frac{\partial w_{01}}{\partial x} + z\frac{\partial \emptyset_x}{\partial x} \qquad \varepsilon_{yy} = \frac{\partial w_{02}}{\partial y} + z\frac{\partial \emptyset_y}{\partial y} \tag{1}$$

$$\gamma_{xy} = \frac{\partial w_{02}}{\partial y} + \frac{\partial w_{02}}{\partial x} + z\left(\frac{\partial \emptyset_x}{\partial y} + \frac{\partial \emptyset_y}{\partial x}\right) \tag{2}$$

$$\gamma_{xz} = \frac{\partial w_{03}}{\partial x} + \emptyset_x\,,\ \gamma_{yz} = \frac{\partial w_{03}}{\partial y} + \emptyset_y\,,\ \varepsilon_{zz} = 0 \tag{3}$$

where w_{01}, w_{02}, w_{03} indicate displacements in x, y and z directions, respectively. $\emptyset_x, \emptyset_y, \emptyset_z$ indicate rotations. In the porosity distribution of core layer, uniform distribution model is used. The porosity is uniformly distributed throughout the height. According to the porous model in core layer, effective material properties (P_C) of core layer such as Young's modulus, Poisson's ratio etc. are given as follows;

$$P_C(a) = P_C(1-a) \tag{4}$$

In equation 4, a (a<<1) indicates the volume fraction of porosity. Constitutive relations of orthotropic plate of layers for nth layer are given as follows:

$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{xy} \end{Bmatrix}^{(n)} = \begin{bmatrix} \overline{Q}_{11} & \overline{Q}_{12} & \overline{Q}_{16} \\ \overline{Q}_{12} & \overline{Q}_{22} & \overline{Q}_{26} \\ \overline{Q}_{16} & \overline{Q}_{26} & \overline{Q}_{66} \end{bmatrix}^{(n)} \begin{Bmatrix} \frac{\partial w_{01}}{\partial x} - z\frac{\partial^2 w_{03}}{\partial x^2} \\ \frac{\partial w_{02}}{\partial y} - z\frac{\partial^2 w_{03}}{\partial y^2} \\ \frac{\partial w_{01}}{\partial y} + \frac{\partial w_{02}}{\partial x} - z\frac{\partial^2 w_{03}}{\partial y^2} - z\frac{\partial^2 w_{03}}{\partial x^2} \end{Bmatrix}^{(n)} \tag{5a}$$

$$\begin{Bmatrix} \sigma_{yz} \\ \sigma_{xz} \end{Bmatrix}^{(n)} = \begin{bmatrix} \bar{Q}_{44} & \bar{Q}_{45} \\ \bar{Q}_{45} & \bar{Q}_{55} \end{bmatrix}^{(n)} \begin{Bmatrix} \frac{\partial w_{02}}{\partial y} - \frac{\partial w_{03}}{\partial y} \\ \frac{\partial w_{01}}{\partial x} - \frac{\partial w_{03}}{\partial x} \end{Bmatrix}^{(n)} \tag{5b}$$

where Q¯_ij indicates the components of stiffness tensor which are presented as follows:

$$\overline{Q}_{11} = Q_{11}cos^4\theta + 2(Q_{12} + 2Q_{66})sin^2\theta cos^2\theta + Q_{22}sin^4\theta$$
$$\overline{Q}_{12} = (Q_{11} + Q_{22} - 4Q_{66})sin^2\theta cos^2\theta + Q_{12}(sin^4\theta + cos^4\theta)$$
$$\overline{Q}_{22} = Q_{11}sin^4\theta + 2(Q_{12} + 2Q_{66})sin^2\theta cos^2\theta + Q_{22}cos^4\theta$$
$$\overline{Q}_{16} = (-2Q_{66} - Q_{12} + Q_{11})sin\theta cos^3\theta + (2Q_{66} - Q_{22} + Q_{12})sin^3\theta cos\theta$$
$$\overline{Q}_{26} = (-2Q_{66} - Q_{12} + Q_{11})sin^3\theta cos\theta + (2Q_{66} - Q_{22} + Q_{12})sin\theta cos^3\theta$$
$$\overline{Q}_{66} = (Q_{22} + Q_{11} - 2Q_{66} - 2Q_{12})sin^2\theta cos^2\theta + Q_{66}(sin^4\theta + cos^4\theta)$$
$$\bar{Q}_{44} = Q_{44}\cos^2\theta + Q_{55}\sin^2\theta$$
$$\bar{Q}_{45} = (Q_{55} - Q_{44})\cos\theta\sin\theta \tag{6}$$

where, θ is fibre orientation angle. Components of the Q_ij are given as follows;

$$Q_{11}=\frac{E_1}{1-\nu_{12}\nu_{21}}\ ,\qquad Q_{22}(T)=\frac{E_2}{1-\nu_{12}\nu_{21}}$$

$$Q_{12}=\frac{\nu_{12}E_2}{1-\nu_{12}\nu_{21}}=\frac{\nu_{21}E_1}{1-\nu_{12}\nu_{21}}\qquad Q_{44}^{(n)}=G_{23}^{(n)}\qquad Q_{55}^{(n)}=G_{13}^{(n)}$$

$$Q_{21}(a)=\frac{\nu_{12}E_2}{1-\nu_{12}\nu_{21}}=\frac{\nu_{21}E_1}{1-\nu_{12}\nu_{21}}\qquad Q_{66}=G_{12} \tag{7}$$

It is noted that the constitiuve relations and material properites of core layer are dependent in porosity according to equation (4). The stress resultants are given as follows;

$$\begin{Bmatrix} N_{xx}\\ N_{yy}\\ N_{xy}\\ M_{xx}\\ M_{yy}\\ M_{xy}\end{Bmatrix}=\begin{bmatrix}\begin{bmatrix}Å_{11} & Å_{12} & Å_{13}\\ Å_{21} & Å_{22} & Å_{23}\\ Å_{31} & Å_{32} & Å_{33}\end{bmatrix} & \begin{bmatrix}ß_{11} & ß_{12} & ß_{13}\\ ß_{21} & ß_{22} & ß_{23}\\ ß_{31} & ß_{32} & ß_{33}\end{bmatrix}\\ \begin{bmatrix}ß_{11} & ß_{12} & ß_{13}\\ ß_{21} & ß_{22} & ß_{23}\\ ß_{31} & ß_{32} & ß_{33}\end{bmatrix} & \begin{bmatrix}Đ_{11} & Đ_{12} & Đ_{13}\\ Đ_{21} & Đ_{22} & Đ_{23}\\ Đ_{31} & Đ_{32} & Đ_{33}\end{bmatrix}\end{bmatrix}\begin{Bmatrix}\frac{\partial w_{01}}{\partial x}\\ \frac{\partial w_{02}}{\partial y}\\ \frac{\partial w_{01}}{\partial y}+\frac{\partial w_{02}}{\partial x}\\ \frac{\partial \emptyset_x}{\partial x}\\ \frac{\partial \emptyset_y}{\partial y}\\ \frac{\partial \emptyset_x}{\partial y}+\frac{\partial \emptyset_y}{\partial x}\end{Bmatrix} \tag{8a}$$

$$\begin{Bmatrix}Q_y\\ Q_x\end{Bmatrix}=K\begin{bmatrix}Å_{44} & Å_{45}\\ Å_{45} & Å_{55}\end{bmatrix}\begin{bmatrix}\frac{\partial w_{03}}{\partial y}+\emptyset_y\\ \frac{\partial w_{03}}{\partial x}+\emptyset_x\end{bmatrix} \tag{8b}$$

where Å_ij is extensional stiffness, ß_ij is extensional – bending stiffness, and Đ_ij is bending stiffness. K indicates the shear correction coefficient;

$$Å_{ij}=\sum_{k=1}^{n}\overline{Q}_{ij}^{(n)}(z_{n+1}-z_n) \tag{9a}$$

$$ß_{ij}=\frac{1}{2}\sum_{k=1}^{n}\overline{Q}_{ij}^{(n)}(z_{n+1}^2-z_n^2) \tag{9b}$$

$$Đ_{ij}=\frac{1}{3}\sum_{k=1}^{n}\overline{Q}_{ij}^{(n)}(z_{n+1}^3-z_n^3) \tag{9c}$$

The governing equations of the problem are presented as follows;

$$\frac{\partial N_{xx}}{\partial x}+\frac{\partial N_{xy}}{\partial y}=0 \tag{10a}$$

$$\frac{\partial N_{xy}}{\partial x}+\frac{\partial N_{yy}}{\partial y}=0 \tag{10b}$$

$$\frac{\partial Q_x}{\partial x}+\frac{\partial Q_y}{\partial y}=0 \tag{10c}$$

$$\frac{\partial M_{xx}}{\partial x}+\frac{\partial M_{xy}}{\partial y}-Q_x=0 \tag{10d}$$

$$\frac{\partial M_{xy}}{\partial x}+\frac{\partial M_{yy}}{\partial y}-Q_y=0 \tag{10e}$$

In solution of the equations, the Navier solution is used. The boundary conditions and displacement of the simply supported plate fields are presented as follows:

$$w_{01}(0,y)=0,\ \ w_{01}(L_x,y)=0,\ \ w_{02}(x,0)=0,\ \ w_{02}(x,L_y)=0, \tag{11a}$$

$$w_{03}(x,0)=0,\ \ w_{03}(x,L_y)=0,\ \ w_{03}(0,y)=0,\ \ w_{03}(L_x,y)=0, \tag{11b}$$

$$\emptyset_x(x,0)=0,\ \ \emptyset_x(x,L_y)=0,\ \ \emptyset_y(0,y)=0,\ \ \emptyset_y(L_x,y)=0, \tag{11c}$$

$$N_{xy}(0,y)=0,\ \ N_{xy}(L_x,y)=0,\ \ N_{xy}(x,0)=0,\ \ N_{xy}(x,L_y)=0 \tag{11d}$$

$$M_{xx}(0,y)=0,\ \ M_{xx}(L_x,y)=0,\ \ M_{yy}(x,0)=0,\ \ M_{yy}(x,L_y)=0 \tag{11e}$$

$$w_{01}(x,y)=\sum_{n=1}^{\infty}\sum_{m=1}^{\infty}U_{1_{mn}} sinkx\ cosly \tag{12a}$$

$$w_{02}(x,y)=\sum_{n=1}^{\infty}\sum_{m=1}^{\infty}U_{2_{mn}} coskx\ sinly \tag{12b}$$

$$w_{03}(x,y)=\sum_{n=1}^{\infty}\sum_{m=1}^{\infty}U_{3_{mn}} sinkx\ sinly \tag{12c}$$

$$\emptyset_x(x,y)=\sum_{n=1}^{\infty}\sum_{m=1}^{\infty}X_{x_{mn}} coskx\ sinly \tag{12d}$$

$$\emptyset_y(x,y)=\sum_{n=1}^{\infty}\sum_{m=1}^{\infty}Y_{y_{mn}} sinkx\ cosly \tag{12e}$$

where $U_{1_{mn}}, U_{2_{mn}}, U_{3_{mn}}, X_{x_{mn}}, Y_{y_{mn}}$ are displacement coefficients, $k=m\pi/L_x$, $l=n\pi/L_y$,

Substituting eqs. (11-12) into eqs. (10) and then using Eigen-value procedures, the algebraic equation of vibration problem is presented as follows;

$$([e]-\omega^2[m])(u)=0 \tag{13a}$$

$$\left(\begin{bmatrix} e_{11} & e_{12} & 0 & e_{14} & e_{15}\\ e_{12} & e_{22} & 0 & e_{24} & e_{25}\\ 0 & 0 & e_{33} & e_{34} & e_{35}\\ e_{14} & e_{24} & e_{34} & e_{44} & e_{45}\\ e_{15} & e_{25} & e_{35} & e_{45} & e_{55}\end{bmatrix} - \omega^2 \begin{bmatrix} m_{11} & 0 & 0 & 0 & 0\\ 0 & m_{22} & 0 & 0 & 0\\ 0 & 0 & m_{33} & 0 & 0\\ 0 & 0 & 0 & m_{44} & 0\\ 0 & 0 & 0 & 0 & m_{55}\end{bmatrix}\right)\begin{Bmatrix} U_{1_{mn}}\\ U_{2_{mn}}\\ U_{3_{mn}}\\ X_{X_{1_{mn}}}\\ Y_{X_{2_{mn}}}\end{Bmatrix} = \begin{Bmatrix}0\\0\\0\\0\\0\end{Bmatrix} \tag{13b}$$

where,

$$e_{11}=(A_{11}k^2+A_{66}l^2),\qquad e_{12}=(A_{12}+A_{66})kl$$

$$e_{13}=0,\quad e_{14}=(B_{11}k^2+B_{66}l^2),\quad e_{15}=(B_{12}+B_{66})kl, e_{22}=(A_{66}k^2+A_{22}l^2),\quad e_{23}=0,$$

$$e_{24}=p_{15},\qquad e_{25}=(B_{66}k^2+B_{22}l^2),$$

$$e_{33}=K(A_{55}k^2+A_{44}l^2)+k_w+G_p(k^2+l^2),$$

$$e_{34}=KA_{55}k,\ e_{35}=KA_{44}l,\quad e_{44}=(D_{11}k^2+D_{22}l^2+KA_{55})$$

$$e_{45}=(D_{12}+D_{66})kl,\quad e_{55}=(D_{66}k^2+D_{22}l^2+KA_{44})$$

$$m_{11}=I_0,\ m_{22}=I_0,\ m_{33}=I_0,\ m_{44}=I_2,\ m_{55}=I_2 \tag{14}$$

The dimensionless fundamental frequency ω ̅, and dimensionless Winkler (̅k_w) and Pasternak (̅G_p) foundation parameters are defined as follows;

$$\overline{\omega}_{mn} = \omega_{mn}({L_y}^2/h)\sqrt{\rho/E_2} \quad (15a)$$
$$\overline{k}_w = k_w {L_x}^4/(E_2 h^3) \quad (15b)$$
$$\overline{G}_p = G_p {L_x}^2/(E_2 h^3) \quad (15c)$$

3. Numerical Results and Discussion

In this section, the dimensionless vibration frequencies of sandwcih plates on Winkler-Pasternak foundation are calculated and presented in figures for different orientation angle of layer, arrengements of face layers and porosity ratios of core layer. The material of face layers are considered as Graphite/Epoxy-T300/934 and its material parameters are E_1=131 GPa, E_2=10.34 GPa, E_3=10.34 GPa, G_{12}=6.895 GPa, G_{23}=6.895 GPa, G_{13}=6.205 GPa, ρ=1627 kg/m^3, ν_{12}= ν_{21}=0.22 [51]. The mechanical properties of core material are considered as E=70 GPa, ν =0.33, ρ=2780 kg/m^3 [19]. The sizes of the plate are taken as follows: $L_x = 1$ m , $L_y = 1$ m, h=0.1 m.

In order validate the presented study and developed formulations, a comparision study performed with the results of some published papers. For this purpose, nondimensional fundamental frequencies are compared with Huang and Zheng [52] and Shoostari and Razavi [53] in table 1. In this comparision study, the materials properties are taken as $E_1/E_2 = 40, G_{12} = G_{13} = 0.6,\ E_2, G_{23} = 0.5,\ E_2, \nu_{12} = 0.25$. Table 1 shows that the results of this study close to the results of Huang and Zheng [52] and Shoostari and Razavi [53].

Table 1. Comparison of dimensionless fundamental frequencies of [0/90/0] square plates on Winkler ($\overline{k}_w$) – Pasternak ($\overline{G}_p$) foundations (a/h=10)

	$\overline{k}_w = 0$ $\overline{G}_p = 0$	$\overline{k}_w = 100$ $\overline{G}_p = 0$	$\overline{k}_w = 100$ $\overline{G}_p = 10$
Huang and Zheng [52]	14.6846	17.7316	22.5693
Shoostari and Razavi [53]	14.8405	17.8953	22.7516
Present study	14.7662	17.8055	22.6371

In figures 2, 3 and 4, dimensionless frequencies with different vibration modes (ω¯_11, ω¯_12, ω¯_21, ω¯_22) are presented for different stacking sequence of layers and foundation parameters. In figures 5 and 6, effects of Winkler (¯k_w) and Pasternak (¯G_p) foundation parameters on dimensionless first fundamental frequencies (ω¯_11) are displayed with different porosity coefficients and stacking sequence of layers.

It is observed from figures 2-4 that vibration frequencies decrease with increasing in porosity parameter significantly. The effects of porosity are very-high on ω¯_12, ω¯_21 vibration modes. In ω¯_12, ω¯_21 vibration modes, the difference among of layers sequences are quite big.

It is observed from figures 5 and 6 that increasing in Winkler and Pasternak foundation coefficients leads to rise the vibration frequencies significiantly. Effects of the Winkler parameters are bigger than that of the Pasternak. Although the Winkler foundation parameters have a little effects on the porosity behavior, the Pasternak foundation is very effectiveon the porosity behavior. It is seen from results that the vibration of sandwich plate can be controlled by porosity and foundation parameters.

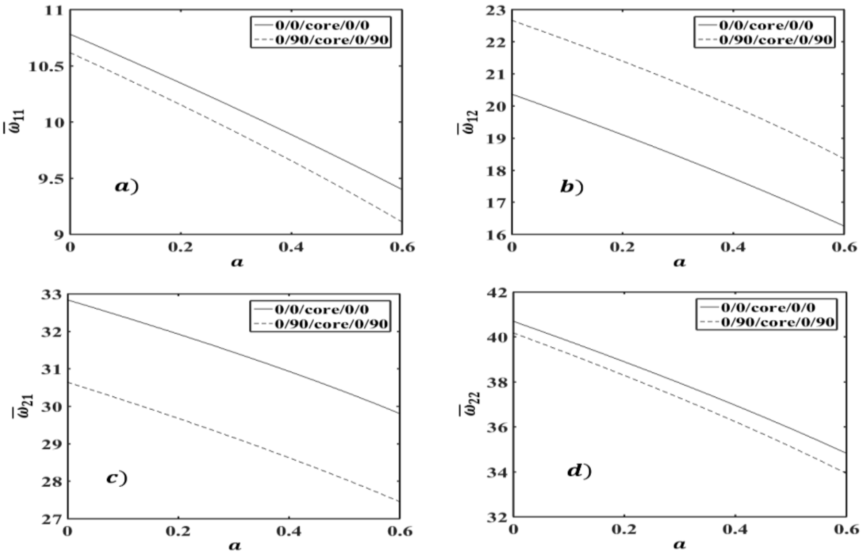


Figure 2. Effects stacking sequence of layers on dimensionless fundamental frequencies of plate with different vibration modes for $\overline{k}_w = 0$, $\overline{G}_p = 0$ for $a)\overline{\omega}_{11}$ $b)\overline{\omega}_{12}$ $c)\overline{\omega}_{21}$ and $d)\overline{\omega}_{22}$

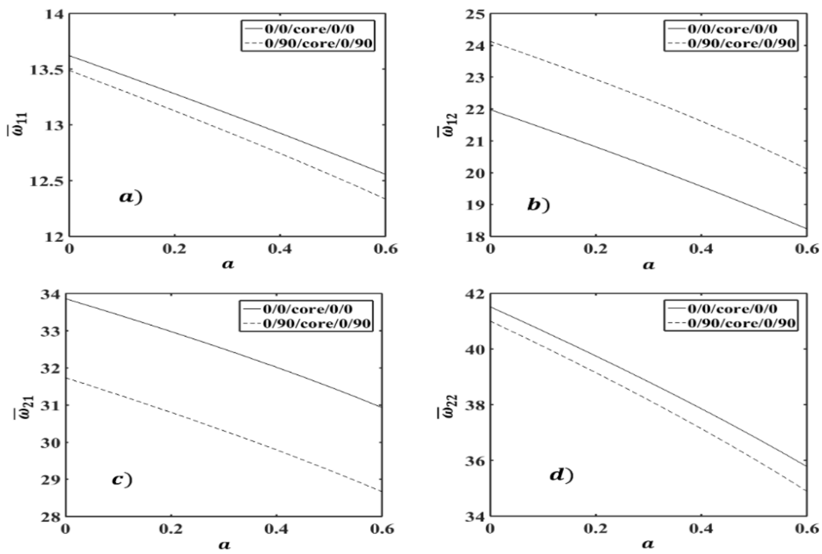


Figure 3. Effects stacking sequence of layers on dimensionless fundamental frequencies of plate wirh different vibration modes for $\overline{k}_w = 100$, $\overline{G}_p = 0$ for $a)\overline{\omega}_{11}$ $b)\overline{\omega}_{12}$ $c)\overline{\omega}_{21}$ and $d)\overline{\omega}_{22}$

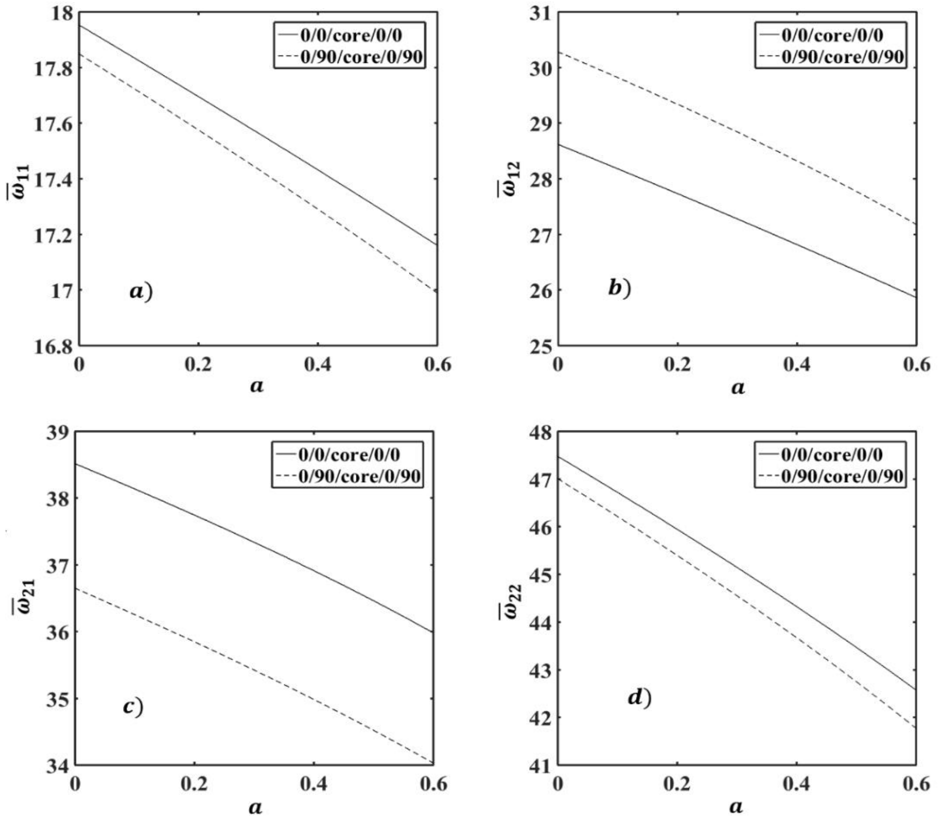
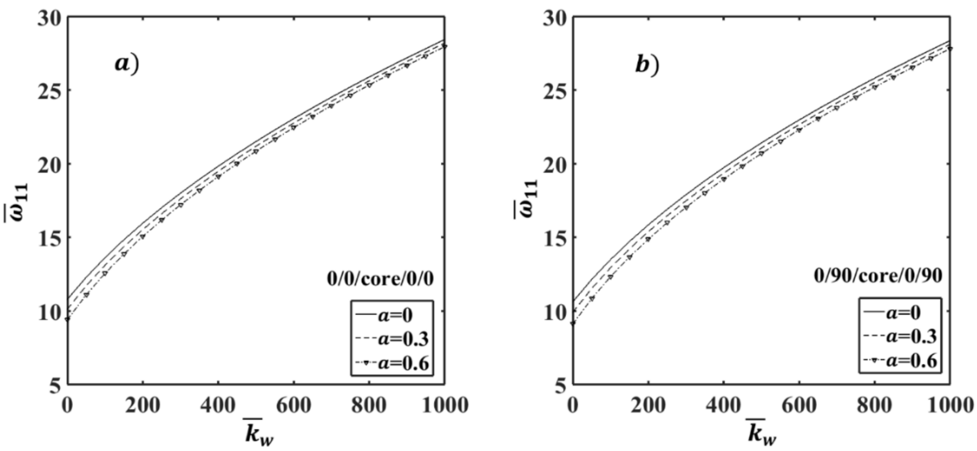
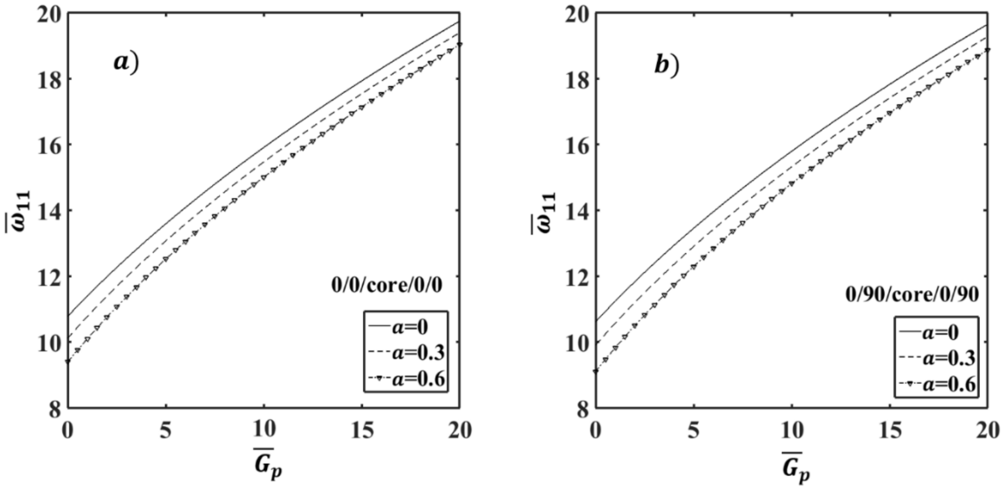


Figure 4. Effects stacking sequence of layers on dimensionless fundamental frequencies of plate wirh different vibration modes for $\overline{k}_w = 100$, $\overline{G}_p = 10$ for $a)\overline{\omega}_{11}$ $b)\overline{\omega}_{12}$ $c)\overline{\omega}_{21}$ and $d)\overline{\omega}_{22}$



Figures 5. Effect of $\overline{k}_w$ on dimensionless fundamental frequency $\overline{\omega}_{11}$ of composite sandwich plate with porosity $a)0/0/\text{core}/0/0$ and $b)0/90/\text{core}/0/90$.



Figures 6. Effect of $\overline{G}_p$ on dimensionless fundamental frequency $\overline{\omega}_{11}$ of composite sandwich plate with porosity $a)0/0/\text{core}/0/0$ and $b)0/90/\text{core}/0/90$.

4. Conclusions

Free vibration analysis of a laminated sandwich plate with porous core layer with elastic foundation is investigated. The composite plate is considered as resting on Winkler-Pasternak foundation. In the kinematic relation of the composite plate, FSDPT is used. Material properties of laminas is considered as orthotropic and core material is porous property. The Navier procedure is used for solution of vibration analysis. The effects sequences of layers, porosity and elastic foundation parameter on the free vibration of the plate are investigated and discussed for different porosity ratios. Results show that the vibration responses of the sandwich plate can be changed with porosity of core layer. With porosity and foundation parameters, the dynamic behavior of the sandwich plate change considerably. Porosity and foundation parameters have significant role on the vibration behaviour of the sandwich plate. The presented method can be make using different soil models and layer arrangement for dynamic analysis in the future.

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