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# Vibration Analysis of Damaged Viscoelastic Composite Sandwich Plate

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**Abstract**

This paper presents a study of free and forced vibration of composite sandwich plate with and without damage using the finite element analysis developed under ANSYS APDL software. This modeling uses the 8-node shell 281 element to modelized the composite laminates of the top and bottom face sheets of the sandwich plate and the 20-node higher order solid 186 element to modelized the viscoelastic core. Two sets of boundaries are considered; Simply supported and clamped boundary conditions at all edges. The effect of damaged face sheets layers on natural frequencies, mode shapes, the frequency and transient responses of the sandwich plate is investigated. Numerical results show remarkable shifts of the natural frequencies, frequency and transient responses due to the presence of damage. It is concluded that the natural frequencies decreasing is due to the loss of structural stiffness. Natural frequencies of the sandwich plates are close to those issued from numerical results available in the literature.

**Keywords**

composite sandwich, vibration plate, damage composite, finite element method, modeling composite, ANSYS

## 1 Introduction

Composite materials are now popular manufacturing materials used for a wide variety of applications. They play a very important role in the automotive, aviation and aerospace industry and are also used for the manufacture of ships, submarines, nuclear and chemical installations, etc. [1]. Damage to laminated fiber-reinforced composites involves fiber breakage, matrix cracking, fiber-matrix debonding and delamination. Delamination is the most common types of damage in laminated composite structures [2]. The rigidity and strength of composite structures are degraded due to the damage. A few models, for example the Progressive Damage Analysis, use strength properties to predict damage initiation, and properties of fracture mechanics to predict the damage evolution [3]. Numerous techniques have been proposed for the simulation or the prediction of composite failure. Many of these techniques have been incorporated into analytical methods and have subsequently been implemented in large simulation software packages or in-house finite element method programs [4]. The progressive damage models are appealing as they are easily implemented in finite element software packages [5]. ANSYS provides progressive damage analysis, the user must utilize APDL commands to identify the damage initiation criteria, the law of damage evolution and the material parameters, as defined in this work. The vibration analysis of laminated composite and laminated composite sandwich with and without damage has been addressed by several authors. Arvin et al. [6] proposed a higher order theory for the calculation of natural frequencies, harmonic and transient responses of composite sandwich beam with viscoelastic core using finite element method. Malekzadeh and Sayyidmousavi [7] presented a free vibration analysis of laminated composite sandwich plate using a finite element model developed in ANSYS Mechanical APDL software. Barkanov [8] studied the transient response of viscoelastic sandwich structures using the finite element method. Bilasse and Oguamanam [9] presented reduced-order finite element model of viscoelastic sandwich plates in forced vibration. Cai et al. [10] presented several methods to include the material damping in ANSYS for harmonic and modal analysis. A finite element analysis method has been developed by Ghosh and Sinha [11] to predict the onset and propagation of damage and to study damaged laminated

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composite plates under forced vibration and impact loads. The free vibration of laminated composite beams with a transverse crack has been investigated by Behera et al. [12] based on the first-order shear deformation theory (FSDT) using a finite element method. Nanda and Sahu [13] computed the natural frequencies and the mode shapes of delaminated composite plates and shells with using a finite element formulation on the basis of FSDT kinematics. Lee [14] studied the influence of lamination angle, position, size, and number of delamination of the delaminated composite plate on the free vibration frequencies using one dimensional layerwise finite element model. Alnefaie [15] calculated numerically the modal and dynamic responses of the laminated composite plate with delamination using 3D finite element method and compared them to experimental results. Sahoo et al. [16] investigated the free vibration, bending, and transient responses of the multilayered composite plates with and without delamination using the HSDT kinematics in conjunction with a finite element modeling.

The literature survey found that very few researches are obtainable on the vibration analysis of the composite sandwich plate with and without damaged face sheets using a finite element model developed in ANSYS Mechanical APDL software. In the present article, free vibration, frequency and transient responses of non-damaged and damaged composite sandwich plate are studied using the progressive damage analysis (PDA) material-model incorporated in ANSYS package. The validity of the proposed modeling is shown by comparing the results (natural frequencies) with the available published literature. The study has been extended to show the applicability of the proposed model to the calculation of the frequency and transient responses of the undamaged and damaged composite sandwich plates with viscoelastic core for different boundary conditions. The key observation is the decrease of natural frequencies and a shift in responses (frequency and transient responses) of damaged composite sandwich plate due to the reduction in structural stiffness.

## 2 Finite element modeling of composite sandwich plate

The ANSYS 15.0 (APDL) finite element software package is used to modelize the viscoelastic composite sandwich plate shown in Fig. 1. In this case, the face sheets (orthotropic layers) are modeled using the shell element SHELL281. Which has 8 nodes with six degrees of freedom at each node: translations in the nodal x, y and z directions (UX, UY, UZ) and rotations about the nodal x, y, and z axes (ROTX, ROTY, ROTZ). While the solid brick element SOLID186 is used for modeling of the viscoelastic core, is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions [17]. Fig. 2 shows the schematic model of the sandwich plate: The shell elements by default place the nodes at the mid-plane of the top and the bottom face-sheets. If the nodes of the shell elements is shared with the solid brick element, half of the factsheets element in the thickness direction would penetrate into the solid brick element [7]. Fig. 3 illustrates the enlarged view of the composite sandwich plate in ANSYS using the shell element SHELL281 (denoted by 1) to modelize the face-sheets and the solid brick element SOLID186 (denoted by 2) to modelize the viscoelastic core [18]. For coupling the degree of

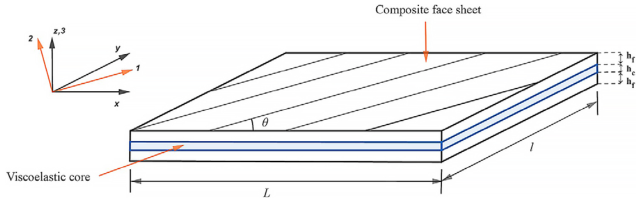



**Fig. 1** General schematic of viscoelastic composite sandwich plate

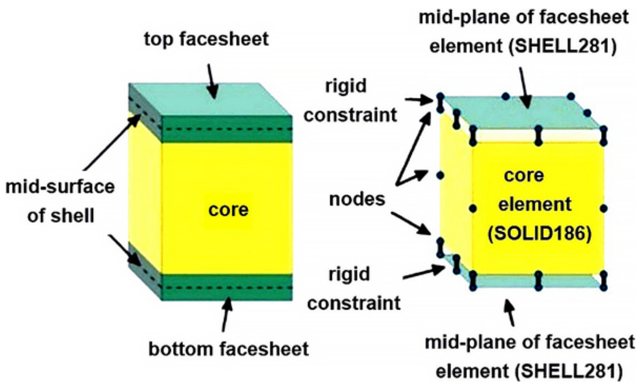



**Fig. 2** A sandwich plate and corresponding finite element model utilizing rigid constraints between the shell and solid elements: adapted from [7, 17]

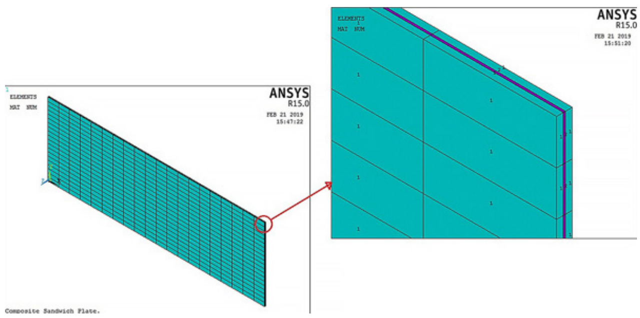



**Fig. 3** Finite element modeling of the composite sandwich plate using the two different element types of ANSYS: adapted from [18]

freedom of shell elements SHELL281 with the degree of freedom of solid brick elements SOLID186, the rigid constraint equations command CERIG developed in APDL Fig. 4 with the following syntaxis used [17]: CERIG, MASTE, SLAVE, Ldof, Ldof2, Ldof3, Ldof4, Ldof5.

In which MASTE and SLAVE are the node numbers for the master and slave nodes, respectively and Ldof, …, Ldof5 are the degree of freedom labels.

## 3 Progressive damage of fiber-reinforced composites in ANSYS

The user must give the properties of linear elastic orthotropic material and two models of material to execute the progressive damage analysis of the composite materials: damage initiation and law of damage evolution.

### 3.1 Damage initiation criteria

The user can define how the progressive damage analysis calculates the onset of material damage using the damage initiation criteria. In ANSYS, the available initiation criteria are Maximum Stress, Maximum Strain, Puck, Hashin, LaRC03, and LaRC04, up to nine additional criteria may be identified as initiation criteria defined by the user. Hashin suggested a ply-by-ply failure criterion for unidirectional composites to model four separate modes of failure associated with fiber damage in tension, in compression, in matrix tensile and in compressive failure [19, 20].

Hashin's criteria have really been widely used in various industries, but they cannot reliably predict the damage mode caused by compression in the matrix. They can be formulated as follows:

- Fiber tension ($\sigma_{11} \geq 0$)

$$F_{ft} = \left(\sigma_{11} / F_{1t}\right)^2 + \alpha\left(\sigma_{12} / F_6\right)^2 = 1, \quad (1)$$

- Fiber compression ($\sigma_{11} < 0$)

$$F_{fc} = \left(\sigma_{11} / F_{1c}\right)^2 = 1, \quad (2)$$

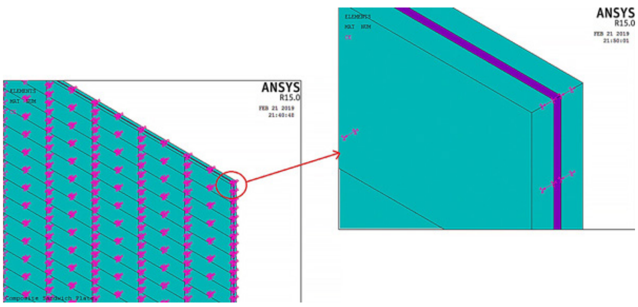



**Fig. 4** The constraints relating the motion of the face sheets to the motion of the core in ANSYS: adapted from [18]

- Matrix tension ($\sigma_{22} \geq 0$)

$$F_{mt} = \left(\sigma_{22} / F_{2t}\right)^2 + \left(\sigma_{12} / F_6\right)^2 = 1, \quad (3)$$

- Matrix compression ($\sigma_{22} < 0$)

$$F_{mc} = \left(\sigma_{22} / 2F_4\right)^2 + \left[\left(F_{2c} / 2F_4\right)^2 - 1\right]\sigma_{22} / F_{2c} + \left(\sigma_{12} / F_6\right)^2 = 1. \quad (4)$$

Where $\sigma_{ij}$ ($i,j$ = 1,2,3) are the stress tensor components, $F_{1t}$ and $F_{1c}$ are the longitudinal tensile and longitudinal compressive strengths of a composite lamina Fig. 5 (b), $F_{2t}$ and $F_{2c}$ are the transverse tensile and the transverse compressive strengths, $F_4$ and $F_6$ represent the intralaminar and in-plane shear strengths. In Eq. (1), The coefficient $\alpha$ is the contribution of the in-plane shear stress to the fiber tensile failure and usually ranges from 0 to 1. For all

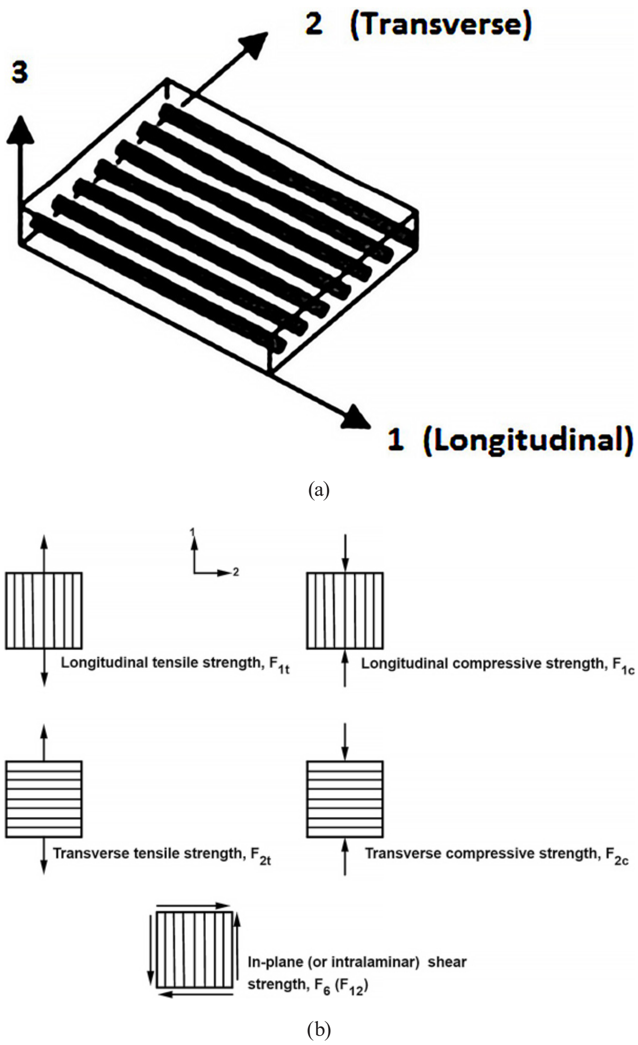



**Fig. 5** (a) Lamina and principal coordinate axes for unidirectional reinforcement, (b) Basic strength parameters of unidirectional lamina for in-plane loading: adapted from [21]

damage modes the ANSYS APDL command for Hashin initiation criteria is TB, DMGI, as shown below:

```
! Damage detection using failure criteria
TB, DMGI, 1, 1, 4, FCRT
TBTEMP,0
! 4 is the value for selecting Hashin criteria, which is here
selected for all four failure modes
TBDATA,1,4,4,4,4.
```

### 3.2 Material strength limits (strength of composite lamina)

For in-plane loading, the lamina Fig. 5 (a) can be defined by five strength parameters as shown in Fig. 5 (b) [21]. These are the longitudinal tensile and the longitudinal compressive strengths, $F_{1t}$ and $F_{1c}$, the transverse tensile and the transverse compressive strengths, $F_{2t}$ and $F_{2c}$, and the in-plane shear strength, $F_6(F_{12})$, plus the interlaminar shear strength. $F_4(F_{23})$ To assess the damage initiation criteria, the user determines the maximum stresses or the maximum strains that can be sustained by the material before damage happens. The requisite inputs depend on the criteria chosen in the part of damage initiation. For example, in the case of Hashin criteria, the user requires to define in-situ compression strength and tensile strength in 1, 2 and 3 lamina directions (named in ANSYS: X, Y and Z directions), and shear strength in planes 12, 13, and 23 of lamina (named in ANSYS: XY, XZ, and YZ planes). The APDL script can define the initial values of in-situ transverse tensile strength $F_{2t}$, in-situ in-plane shear strength $F_6$, and intralaminar shear strength $F_4$ (named in ANSYS: XT, XY, and XZ). TB, FCLI is the command of the material strength limit,as shown below [22–24]:

```
TB, FCLI,1,1,6          ! Material Strengths
TBTEMP,0
TBDATA,1, F_1t          ! Failure Stress, Fiber Tension
TBDATA,2, F_1c          ! Failure Stress, Fiber Compression
TBDATA,3, F_2t          ! Failure Stress, Matrix Tension
TBDATA,4, F_2c          ! Failure Stress, Matrix Compression
TBDATA,7, F_6           ! Failure Stress, XY Shear
TBDATA,8, F_4           ! Failure Stress, YZ Shear
```

### 3.3 Damage evolution criteria

Generally, carbon fiber/epoxy laminates typically show fragile properties as damage progresses. For Predicting the damage behavior of the composites, the law of damage evolution is usually defined to degrade the stiffness of material after different modes of damage initiation are already satisfied [25]. ANSYS provides two options (methods) for the evolution of damage [15, 26–28]: continuum damage mechanics (CDM) and instant stiffness reduction (MPDG). In the method MPDG, the amount of reduction depends on the variables of damage defined in the damage evolution law, in which coefficient values are addressed to the reduction of tensile fiber stiffness $d_f^+$, reduction of compressive fiber stiffness $d_f^-$, reduction of tensile matrix stiffness $d_m^+$ and reduction of compressive matrix stiffness $d_m^-$. The values of these coefficients can range between corresponds to no damage (no stiffness reduction) and corresponds to a complete damage. In this study, a value of has been considered for all variables of damage. TB, DMGE is the command for defining the damage evolution in ANSYS APDL, as shown below:

```
!DAMAGE EVOLUTION (DMGE)
TB, DMGE,1,1,4, MPDG    ! Damage Evolution with MPDG Method
TBTEMP,0
TBDATA,1, d_f^+         ! Reduction of tensile fiber stiffness
TBDATA,2, d_f^-         ! Reduction of compressive fiber stiffness
TBDATA,3, d_m^+         ! Reduction of tensile matrix stiffness
TBDATA,4, d_m^-         ! Reduction of compressive matrix
                          stiffness
```

## 4 Numerical results and discussion

In this section, a sandwich plate with viscoelastic core and composite face sheets has been considered. The face sheets (orthotropic lamina) material is carbon–epoxy (T700/3234). Geometrical and mechanical properties of the plate are shown in Fig. 1 and Table 1 A viscoelastic core with a constant complex modulus is considered with:

$$E_c = E_0\left(1 + i\eta_c\right) \tag{5}$$

Where $E_0$ is the storage modulus and $\eta_c$ is the loss factor of the viscoelastic core. Orthotropic faces (composite lamina) are varying with $\theta$ fiber orientation angle. By using the finite element model mesh of ANSYS APDL described in the second section, all the three layers are modelized with 20 elements through the width and 20 elements along the length, as shown in Fig. 6 (a). The boundary conditions for the rectangular sandwich plate are as follows: SSSS signifies a sandwich plate that is simply supported on all four sides as shown in Fig. 6 (b) and CCCC signifies a sandwich plate that is clamped on all four sides.

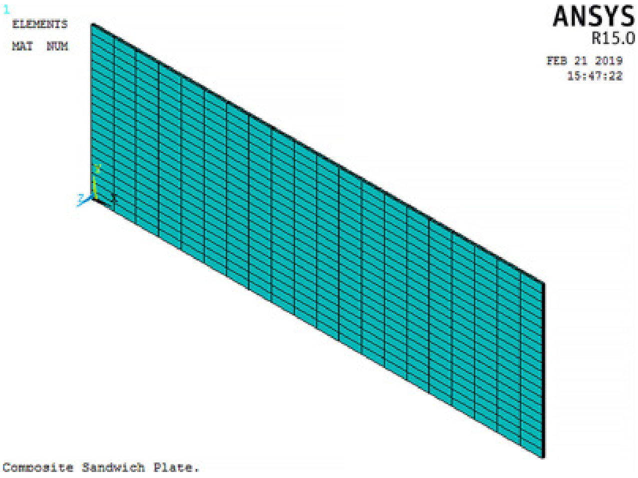
**Table 1** Geometrical and mechanical properties of sandwich plate with composite face sheets and viscoelastic core: adapted from [4]

| Geometrical proprieties | | | |
|---|---|---|---|
| Face sheets thickness $h_f$ (mm) | Core thickness $h_C$ (mm) | Plate length $L$ (mm) | Plate width $l$ (mm) |
| 0.762 | 0.254 | 300 | 100 |

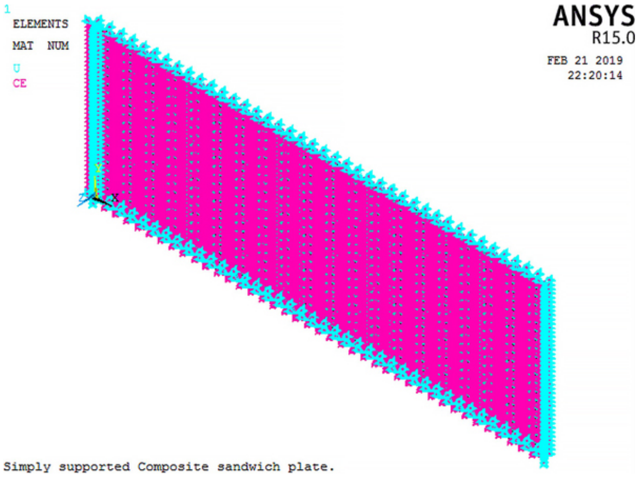
| Faces sheets orthotropic proprieties (T700/3234) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $E_1$ (GPa) | $E_2$ (GPa) | $E_3$ (GPa) | $G_{12}$ (GPa) | $G_{23}$ (GPa) | $G_{13}$ (GPa) | $v_{12}$ | $v_{23}$ | $v_{13}$ | $\rho_f$ (Kg/m$^3$) |
| 119 | 8.7 | 8.7 | 4 | 3 | 4 | 0.32 | 0.3 | 0.32 | 1560 |

| Strength of composite lamina (T700/3234) | | | | | |
|---|---|---|---|---|---|
| $F_{1t}$ (MPa) | $F_{1c}$ (MPa) | $F_{2t}$ (MPa) | $F_{2c}$ (MPa) | $F_6$ (MPa) | $F_4$ (MPa) |
| 2100E6 | –870E9 | 35E6 | –120E6 | 40E6 | 50E6 |

| Core viscoelastic proprieties | | | | |
|---|---|---|---|---|
| Young modulus $E_c$ (MPa) $E_c = E_0 (1 + i\eta_c)$ | Storage modulus $E_0$ (MPa) | Loss factor $\eta_c$ | Density $\rho_c$ (Kg/m$^3$) | Poisson's ratio $\upsilon_c$ |
| | 2670.08 | 0.5 | 999 | 0.49 |




(a)




(b)

**Fig. 6** (a) Meshing of the composite sandwich plate with 20 × 20 elements for each layer, (b) Simply-supported composite sandwich plate finite element model (meshing, constraints relating and boundary conditions)

### 4.1 Free vibration analysis

Modal analysis is performed to calculate the natural frequencies and mode shapes of a composite sandwich plate with and without damage using the Block Lanczos method of the ANSYS APDL software. The influences of fiber angles of face sheets $\theta$ are studied. Hence, fiber angles of face sheets are varied between 0° and 90°. Comparative results of the first three natural frequencies of the undamaged composite sandwich plate are presented in Tables 2 and 3. The results of the SSSS and CCCC plates are in good

**Table 2** Natural frequencies (Hz) of the first three modes for the undamaged simply supported composite sandwich plate

| Angle $\theta$ | | Mode 1 | Mode 2 | Mode 3 |
|---|---|---|---|---|
| $\pi/2$ | Present Method ANSYS | 343.62 | 361.12 | 396.19 |
| | FEM: adapted from [4] | 343.96 | 360.22 | 395.50 |
| | ABAQUS: adapted from [4] | 339.24 | 358.27 | 396.03 |
| $3\pi/8$ | Present Method ANSYS | 313.11 | 340.89 | 390.44 |
| | FEM: adapted from [4] | 311.37 | 338.34 | 388.59 |
| | ABAQUS: adapted from [4] | 306.34 | 336.47 | 389.31 |
| $\pi/4$ | Present Method ANSYS | 249.26 | 307.39 | 392.86 |
| | FEM: adapted from [4] | 243.76 | 302.21 | 389.30 |
| | ABAQUS: adapted from [4] | 240.57 | 300.98 | 388.92 |
| $\pi/8$ | Present Method ANSYS | 194.88 | 277.68 | 399.45 |
| | FEM: adapted from [4] | 193.10 | 274.71 | 397.97 |
| | ABAQUS: adapted from [4] | 191.50 | 273.66 | 396.77 |
| 0 | Present Method ANSYS | 170.78 | 248.50 | 396.21 |
| | FEM: adapted from [4] | 172.56 | 249.38 | 396.54 |
| | ABAQUS: adapted from [4] | 171.62 | 248.96 | 396.65 |

**Table 3** Natural frequencies (Hz) of the first three modes for the undamaged clamped composite sandwich plate

| Angle $\theta$ | | Mode 1 | Mode 2 | Mode 3 |
|---|---|---|---|---|
| | Present Method ANSYS | 684.75 | 696.97 | 721.11 |
| $\pi/2$ | FEM: adapted from [4] | 690.88 | 702.77 | 726.4 |
| | ABAQUS: adapted from [4] | 683.36 | – | 727.25 |
| | Present Method ANSYS | 604.13 | 622.77 | 657.84 |
| $3\pi/8$ | FEM: adapted from [4] | 609.34 | 627.84 | 662.71 |
| | ABAQUS: adapted from [4] | 602.86 | 623.74 | 663.34 |
| | Present Method ANSYS | 427.39 | 474.24 | 551.28 |
| $\pi/4$ | FEM: adapted from [4] | 430.79 | 477.95 | 555.45 |
| | ABAQUS: adapted from [4] | 427.84 | 478.42 | 555.85 |
| | Present Method ANSYS | 303.29 | 385.98 | 515.88 |
| $\pi/8$ | FEM: adapted from [4] | 306.59 | 389.39 | 519.78 |
| | ABAQUS: adapted from [4] | 304.33 | 390.22 | 520.02 |
| | Present Method ANSYS | 276.44 | 360.79 | 524.00 |
| 0 | FEM: adapted from [4] | 279.79 | 363.52 | 526.28 |
| | ABAQUS: adapted from [4] | 278.07 | 363.64 | 527.48 |

accordance with the numerical results of the literature [4]. Then, the natural frequencies of the first mode of vibration for undamaged composite sandwich plate in simply supported and clamped boundary conditions are shown in Fig. 7 (a) and (b) respectively and comparedto reference article [4]. It can be seen that by increasing the fiber angles of face sheets, natural frequencies are increasing. It is observed from Fig. 7 (a) and (b) that the natural frequencies are higher in clamped plate as compared to simply supported plate. In the present study, a value of has been considered for all the damage variables. The natural frequencies of the damaged composite sandwich plate for simply supported and clamped boundary conditions are shown in Tables 4 and 5 respectively. The first five natural frequencies of the composite sandwich plate for 0° fiber angle orientation in simply supported and clamped boundary conditions are shown in Fig. 8 (a) and (b). It is observed from Fig. 8 (a) and (b) that the natural frequencies of damaged composite sandwich are decreasing in comparing to the natural frequencies of undamaged plate. The decreasing in natural frequencies due to the reduction in stiffness of the plate. The first three displacement mode shapes of the composite sandwich plate with and without damage for simply supported and clamped boundary conditions are shown in Figs. 9 and 10 respectively. Changes in the displacement mode shapes between the undamaged and damaged case are observed, mode shapes in damaged case are greater than those for mode shapes in undamaged case. Therefore, the decrease in stiffness is associated with reduction in the natural frequencies and modification of the structural vibration modes.

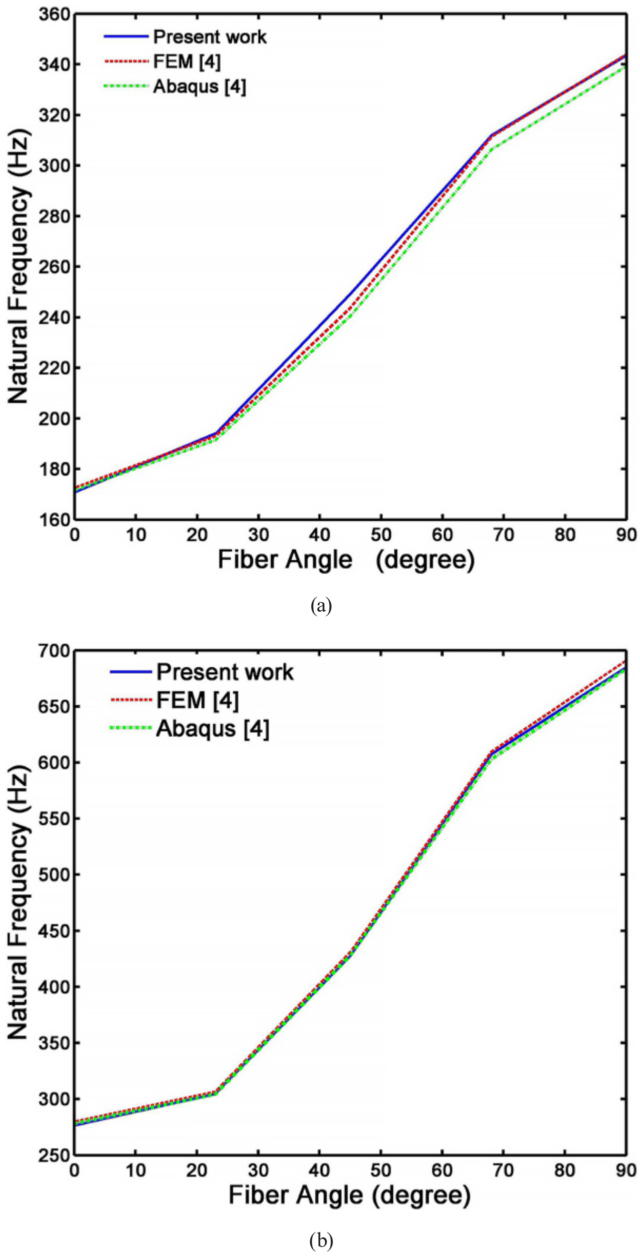



**Fig. 7** Influences of face sheets fiber angle (°) of the undamaged viscoelastic composite sandwich plate on natural frequencies of the first mode of vibration: (a) simply supported boundary condition, (b) clamped boundary condition

**Table 4** Natural frequencies (Hz) of the first five modes for undamaged and damaged simply supported composite sandwich plate

| Angle $\theta$ | Present Method ANSYS | Mode 1 | Mode 2 | Mode 3 | Mode 4 | Mode 5 |
|---|---|---|---|---|---|---|
| $\pi/2$ | Undamaged case | 343.62 | 361.12 | 396.19 | 451.28 | 526.42 |
| | Damaged case | 342.22 | 359.43 | 394.13 | 448.83 | 523.52 |
| $3\pi/8$ | Undamaged case | 313.11 | 340.89 | 390.44 | 461.83 | 553.40 |
| | Damaged case | 311.80 | 339.33 | 388.54 | 459.53 | 550.64 |
| $\pi/4$ | Undamaged case | 249.26 | 307.39 | 392.86 | 499.33 | 623.36 |
| | Damaged case | 248.22 | 306.18 | 391.33 | 497.29 | 620.65 |
| $\pi/8$ | Undamaged case | 194.88 | 277.68 | 399.45 | 516.54 | 556.71 |
| | Damaged case | 194.05 | 276.61 | 397.84 | 514.11 | 554.24 |
| 0 | Undamaged case | 170.78 | 248.50 | 396.21 | 466.41 | 514.7 |
| | Damaged case | 170.03 | 247.24 | 394.16 | 464.82 | 512.40 |

**Table 5** Natural frequencies (Hz) of the first five modes for undamaged and damaged clamped composite sandwich plate

| Angle $\theta$ | Present Method ANSYS | Mode 1 | Mode 2 | Mode 3 | Mode 4 | Mode 5 |
|---|---|---|---|---|---|---|
| $\pi/2$ | Undamaged case | 684.75 | 696.97 | 721.11 | 760.29 | 816.98 |
| | Damaged case | 681.43 | 693.48 | 717.37 | 756.24 | 812.53 |
| $3\pi/8$ | Undamaged case | 604.13 | 622.77 | 657.84 | 712.27 | 787.72 |
| | Damaged case | 601.06 | 619.54 | 654.35 | 708.45 | 783.47 |
| $\pi/4$ | Undamaged case | 427.39 | 474.24 | 551.28 | 655.79 | 784.5 |
| | Damaged case | 425.01 | 471.73 | 548.49 | 652.54 | 780.59 |
| $\pi/8$ | Undamaged case | 303.29 | 385.98 | 515.88 | 677.41 | 708.32 |
| | Damaged case | 301.84 | 384.23 | 513.50 | 674.03 | 704.39 |
| 0 | Undamaged case | 276.44 | 360.79 | 524 | 624.49 | 681.03 |
| | Damaged case | 275.46 | 359.19 | 521.43 | 622.09 | 677.88 |

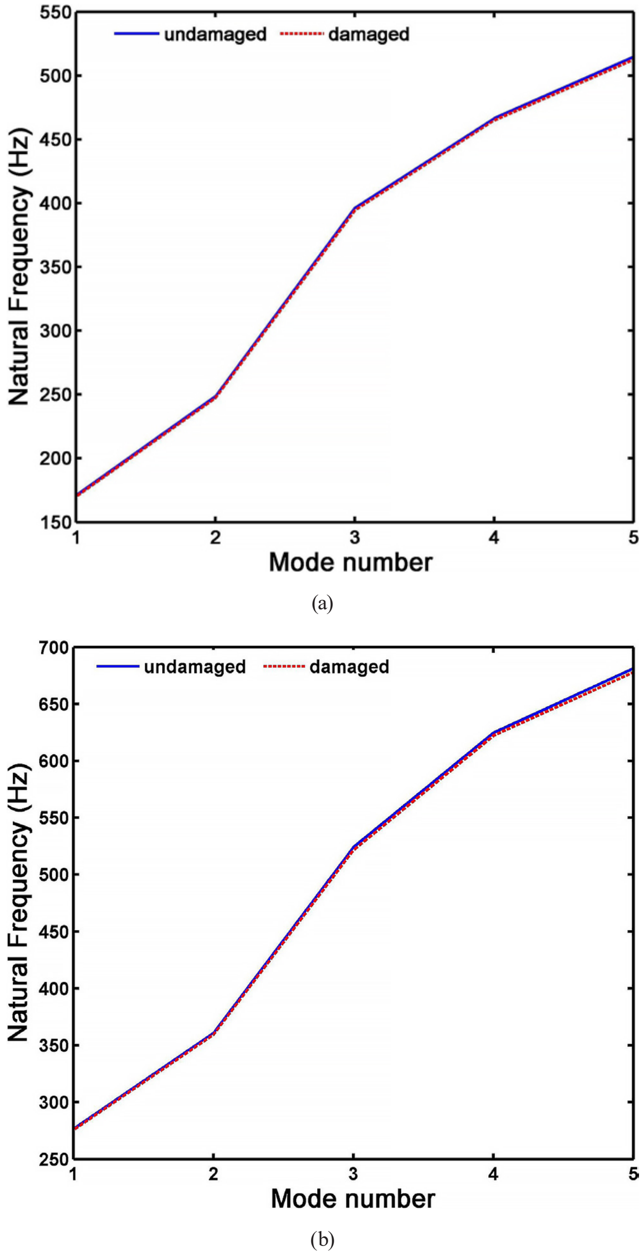



**Fig. 8** Comparative natural frequencies of the first five mode of vibration for undamaged and damaged viscoelastic composite sandwich plates and $\theta = 0°$: (a) for simply supported boundaries, (b) for clamped boundaries

## 4.2 Harmonic vibration analysis (frequency response analysis)

Harmonic analysis of viscoelastic composite sandwich plate is solved in ANSYS for undamaged and damaged cases, finite elements of ANSYS program using the full method (the full method uses the full system matrices) to calculate the frequency response function (FRF). To determine the response, a force of 10 N is exerted at the node position $((L/2, l/2),$

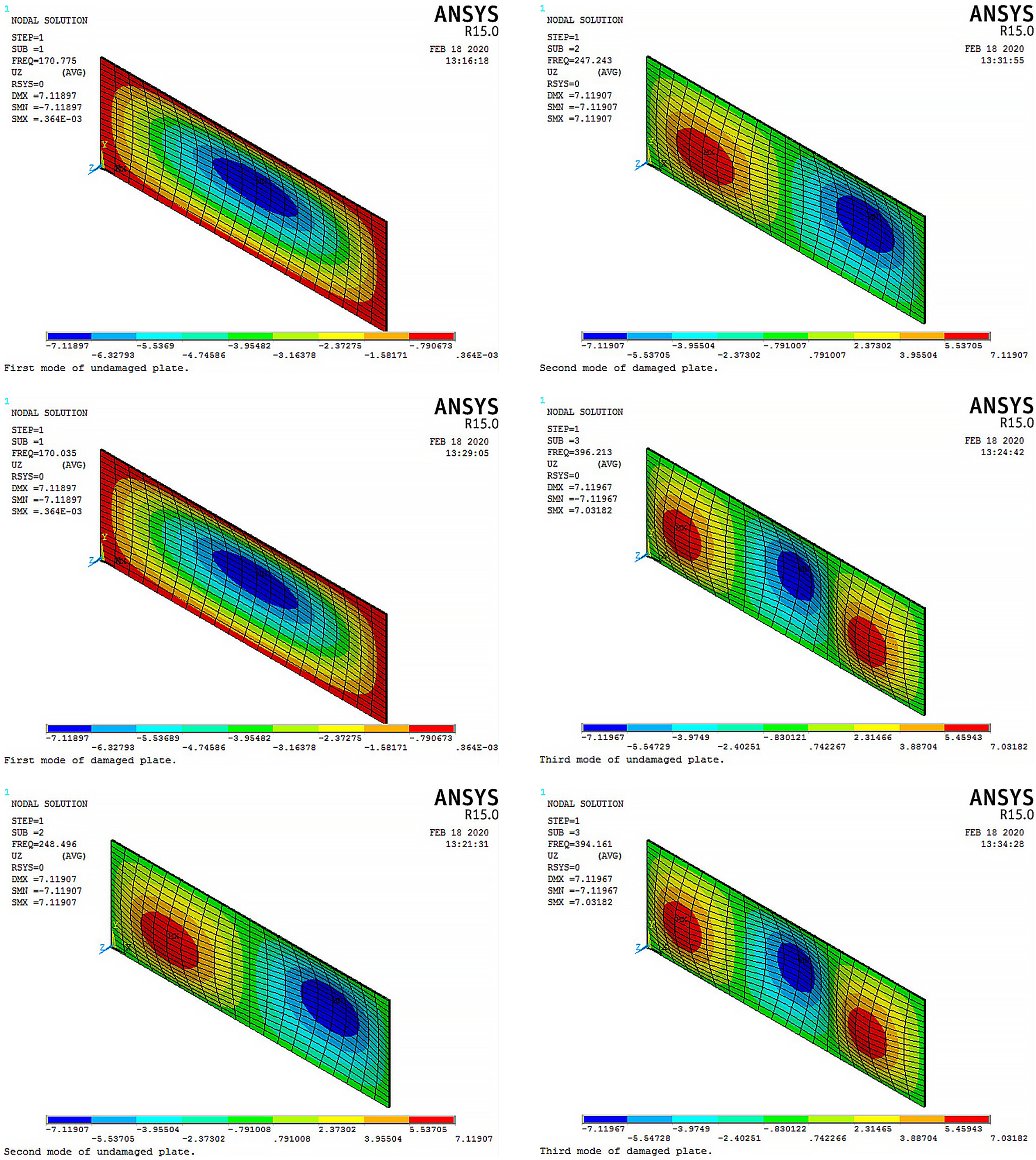



**Fig. 9** The first three mode shapes of the undamaged and damaged simply supported composite sandwich plate for $\theta = 0°$

node no.2002) of the sandwich plate for a frequency range of 0–2500 Hz [9, 24, 29, 30]. Figs. 11 and 12 show the frequency responses of the undamaged and damaged composite sandwich plates at the plate center $P$ (($L$/2,$l$/2), node no. 2002) for both simply supported and clamped boundary conditions respectively. The presence of damage results in a decreasing of the structure rigidity which, in turn, affects the dynamic characteristics of the plate. The graph shows that the difference in the frequency response curves between undamaged and damaged composite sandwich plates appears clearly and

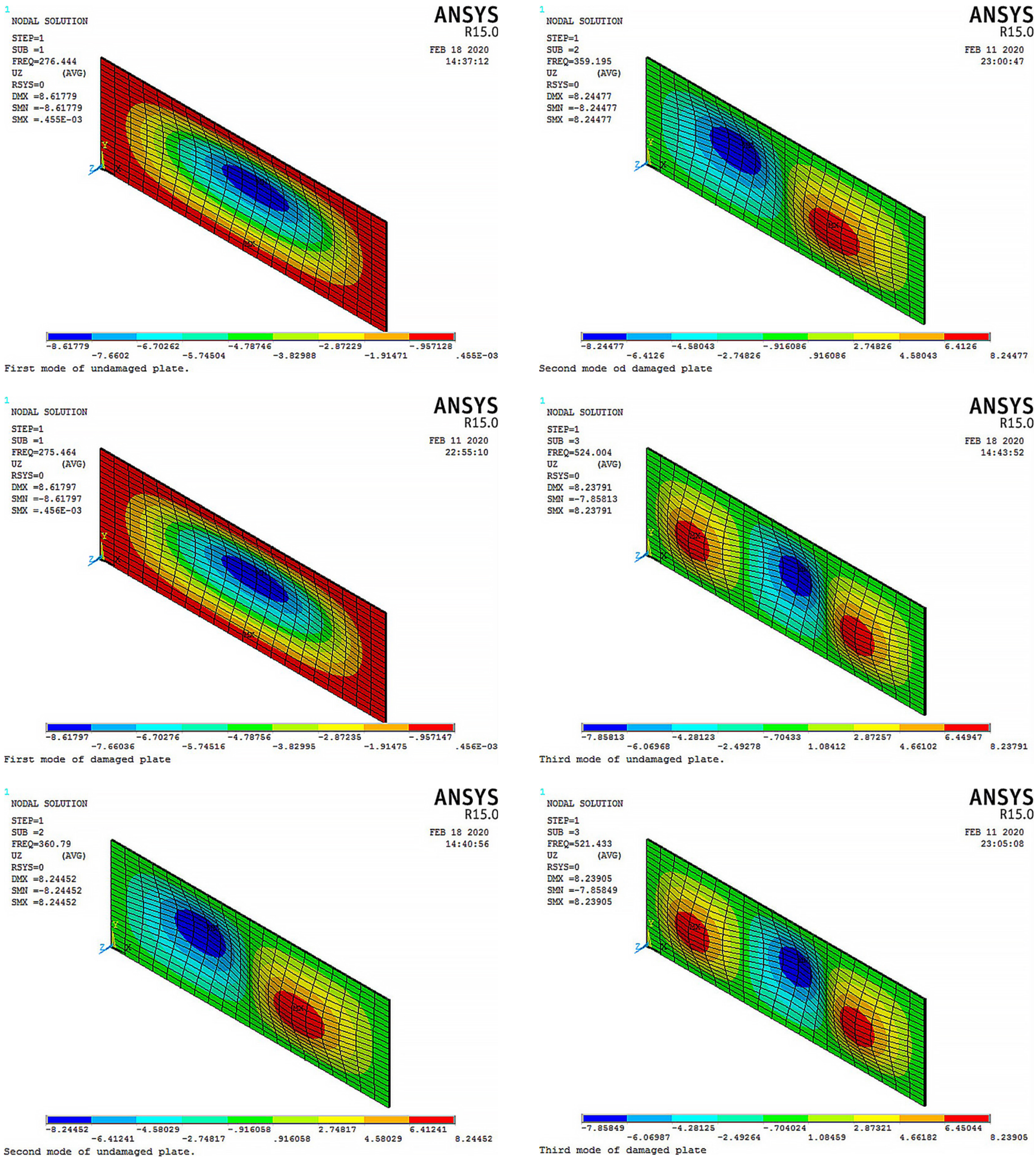



**Fig. 10** The first three mode shapes of the undamaged and damaged clamped composite sandwich plate for $\theta = 0°$

the shift in natural frequencies can be clearly defined. In summary, the presence of damage in the face sheets reduces the natural frequencies of the plate, particularly for those of higher natural frequencies. It is observed from Figs. 11 and 12 that the frequency response of simply supported sandwich plate is greater than the frequency response of clamped one.

### 4.3 Transient vibration analysis

The simply supported composite sandwich plate is subjected to an impulse load at a point $P$ (($L/2$,$l/2$) at node no. 2002). The load is 12 N, in the positive z-direction and is exerted for 0.01 s. Three load steps with ramped loading are used; as can be seen in Fig. 13, the times at the end

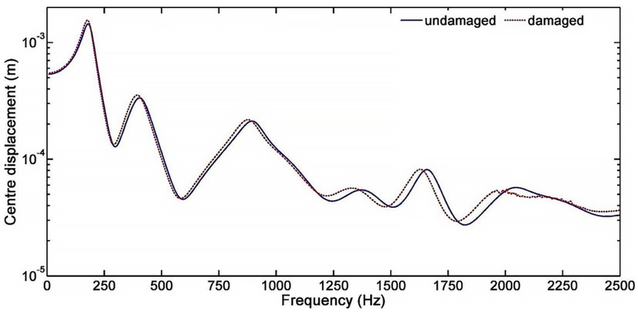



**Fig. 11** Frequency response of simply supported viscoelastic composite sandwich plate in point $P$ ($L$/2,$l$/2) for the undamaged and damaged cases with $\theta = 0°$

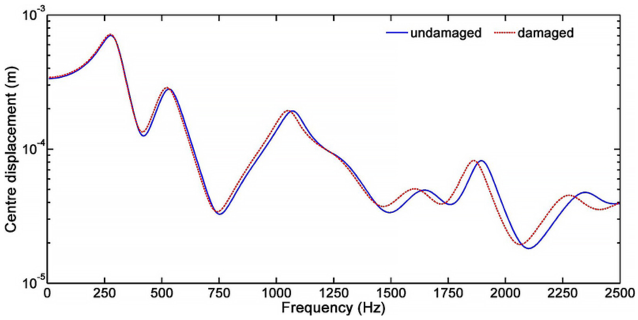



**Fig. 12** Frequency response of clamped viscoelastic composite sandwich plate in point $P$ ($L$/2,$l$/2) for the undamaged and damaged cases with $\theta = 0°$

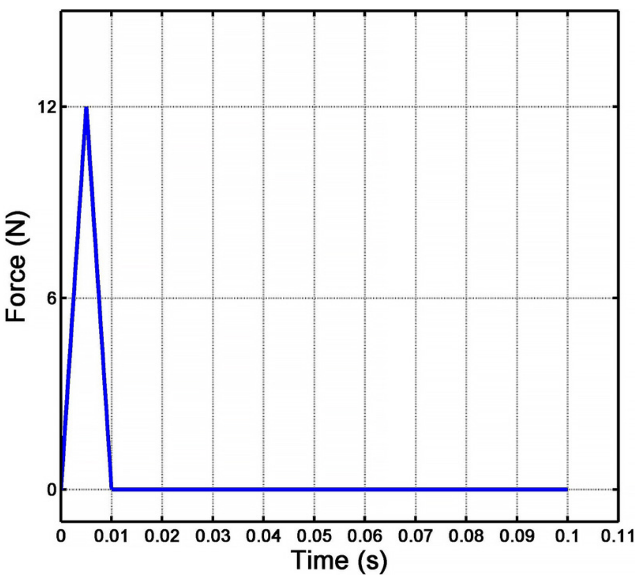



**Fig. 13** Impulse load

of the first, second and third load steps are 0.005, 0.01 and 0.1 s, respectively, with a time step of 1E–4 s [8, 17]. The aim is to obtain the time response (transient response) of the sandwich plate in the point $P$, Fig. 14 shows the time response of the viscoelastic composite sandwich plate for undamaged and damaged cases. Fig. 14 shows a comparison of the transient responses of the composite sandwich plate with and without damage under the same load.

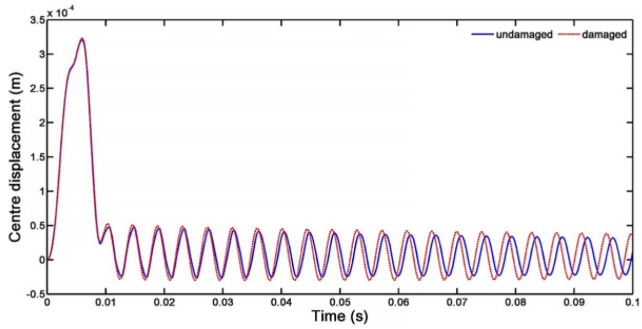



**Fig. 14** Transient response of simply supported viscoelastic composite sandwich plate in point $P$ ($L$/2,$l$/2) for the undamaged and damaged cases with $\theta = 0°$

It is observed from Fig. 14 that the transient response of the damaged composite sandwich plate is greater than the transient response of the undamaged composite sandwich plate. A phase shift is shown as time progresses, indicating the shift in natural frequency as seen in Fig. 14. This is evidently attributed to a decrease in the stiffness of the damaged plate.

## 5 Conclusion

In this paper, ANSYS APDL finite element modeling is developed for the computation of the natural frequencies, the frequency and the transient responses of the composite sandwich plate with and without damage for simply supported and clamped boundary conditions. The following conclusions can be made from the present study:

1. A decreasing in the natural frequencies of sandwich composite plate is due to the damaged face sheets layers of sandwich plate.
2. It is observed that the displacement mode shapes of composite sandwich plate in damaged case are greater than those for displacement mode shapes in undamaged case.
3. The natural frequencies of the composite sandwich plate (in damaged and undamaged cases) are highly dependent on the boundary conditions.
4. The obtained results show that by increasing the fiber angles of face sheets, natural frequencies are increasing for $0° \leq \theta \leq 90°$.
5. It is observed that the frequency and transient responses of composite sandwich plate in damage case is shifted to left in comparison to those in undamaged one.
6. The frequency and transient responses of composite sandwich plate increase because of structural stiffness reduction.

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