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Eigen-Frequency Behavior of Sandwich Plate with Cutout

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Abstract——*The frequency characteristics of a flat sandwich panel with a cutout are examined in the present work using lower-order theory in conjunction with the finite element method. First of all, the sandwich flat panel with the cutout is created in ANSYS software using ANSYS parametric design language (APDL) code. Further, the panel is divided into small parts using the eight-noded quadrilateral shell element (SHELL281) from the ANSYS library. The material properties of the core and face sheet are assigned. Later on, the edge constraint condition is applied at all the boundaries. Now, the simulated sandwich panel is analyzed for frequency characteristics. Initially, the present numerical model has been validated by comparing the present responses with that of the previously published responses. After the validation study, the numerical model has been used to investigate the influence of cutouts shape and size, mode shape, boundary conditions as well as geometrical properties on the vibration responses of the sandwich structure via different numerical illustrations. Based on the numerical illustration different observations have been discussed in detail.*

INTRODUCTION

Sandwich composite materials are superior than traditional materials in terms of specific strength, stiffness, and weight ratio. These materials are both heat-resistant and strong enough to use in demanding environments. Sandwich composites are made up of two layers of thinner and stronger face sheets that are adhered together with one thicker and weaker core. The face sheet handles tension and compressive stress during bending, while the core of the sandwich composite, which can handle shear stress, supports both face sheets so they don't move (inward or outward) and stay in the same place.

A cutout is simply a hole or opening that serves a structural purpose, such as providing ventilation, lowering weight, or allowing passage of access components in the mechanical, civil, and aerospace industries. The existence of a cutout in a composite structure has a substantial influence on its stability. Consequently, it is crucial to examine the impact of various cutout on the structural properties of the sandwich structure. In the following paragraph, several relevant works on the sandwich and layered composite panels are discussed for a better understanding of the research theme.

Wang et al.[1] applied 2D and 3D FE models to examine the frequency behaviour of a multilayered sandwich panel with a honeycomb core. The dynamic responses of a flat sandwich panel are investigated by Nayak et al. [2] by Reddy's third-order shear deformation theory (HSDT). Likewise, Serdoun and Cherif [3] also used Reddy's theory to study the natural frequency behavior of sandwich composite plates. Meunier and Shenoi [4] explored the natural frequency behavior of sandwich panels by utilizing both the first and higher-order theory of Reddy's. Elmalich and Rabinovitch [5] investigated the dynamic analysis of the sandwich structure with softcore by using the finite element (FE) steps. The frequency characteristics of a layered sandwich composite structure have been examined by Burlayenko and Sadowski [6] by applying the FE package (ABAQUS). Kant and Swaminathan studied dynamic responses of a layered and flat sandwich composite panel by higher-order refined theory subjected to[7] simply supported boundary conditions. Farsani et al.[8] used HSDT for investigating model characteristics of a sandwich structure with a compressible core under various end conditions. Sekine et al. [9] focused on a sandwich composite plate with a honeycomb core. They used lay-up optimization on face skin and found maximum fundamental frequencies in-plane shear coupling. Senthilkumaran et al. [10] focused to explore the frequency responses of the sandwich beam having a cutout by using FE steps. Reddy [11] presented a model response of a layered flat composite panel with a cutout using the FE method and lower-order theory (FSDT). Hadji and Avcar [12] investigate the model response of sandwich panels with isotropic core and functionally graded (FG) face skin.

According to the above literature, there is relatively little work has been conducted on FE modelling of sandwich composite flat panels with various cutouts parameters. This research aims to numerically analyze the frequency characteristics of the sandwich plate with cutout utilizing the commercial FE tool

(ANSYS) via the APDL code. In addition, the reliability of the present FE model has been validated by calculating frequency responses and comparing them to previously published literature. Finally, the impact of the cutout parameters on the eigen-frequency responses of the flat sandwich composite panel has been reported and thoroughly discussed.

MATHEMATICAL FORMULATION

Displacement field

Fig. 1 shows a square sandwich flat panel with concentric arbitrary cutout whose geometrical characteristics are described as plate length, width, and overall thickness by letters 'l', 'b' and 'h' in x_1, y_2 and ς_3 axis respectively. It is made up of 'N' layers of face sheets, and the overall thickness is computed by adding the face sheet (h_f) and core (h_c) thicknesses. The APDL code has been implemented in ANSYS to create a simulation model. On the basis of the FSDT, the displacement field equation of the layered sandwich panel is considered and expressed as:

$$\left.\begin{aligned} u(x_1,y_2,\varsigma_3) &= \bar{u}(x_1,y_2)+\varsigma_3\theta_{x_1}(x_1,y_2) \\ v(x_1,y_2,\varsigma_3) &= \bar{v}(x_1,y_2)+\varsigma_3\theta_{y_2}(x_1,y_2) \\ w(x_1,y_2,\varsigma_3) &= \bar{w}(x_1,y_2)+\varsigma_3\theta_{\varsigma_3}(x_1,y_2) \end{aligned}\right\} \quad (1)$$

where letters u, v and w indicate the displacement all along the x_1, y_2, ς_3 directions, respectively. Similarly, symbols $\bar{u}, \bar{v}$ and $\bar{w}$ show the corresponding displacement at any position in the midplane. Rotation axes in the midplane are denoted by θ_{x_1} and θ_{y_2}.

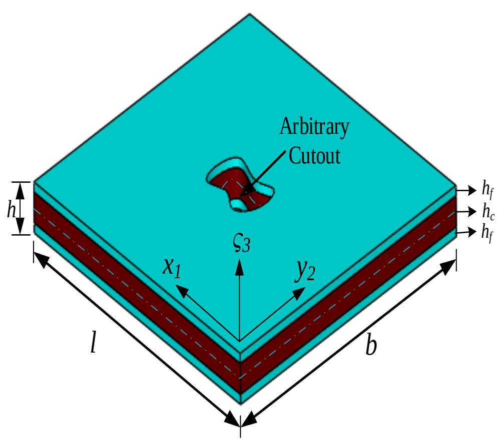

Figure 1: Geometrical model of sandwich plate with arbitrary cutout.

Constitutive relations

The constitutive relationships for any kth layer of the layered sandwich composite are now mathematically defined as:

$$\{\sigma_{ij}\}_k = [\bar{Q}_{ij}]_k \{\varepsilon_{ij}\}_k \quad (2)$$

here $\{\sigma_{ij}\}, [\bar{Q}_{ij}]$ and $\{\varepsilon_{ij}\}$ are refers to stress, reduced transformation stiffness and strain tensor, respectively.

Finite element formulation

The developed model is converted into small parts using eight-noded (Shell 281) elements in ANSYS based on displacement field variables. The displacement field vector "λ" is written as follows:

$$\{\lambda\} = \sum_{i=1}^{n}[N_i]\{\lambda_i\} \quad (3)$$

where $\{\lambda_i\} = \{\bar{u}, \bar{v}, \bar{w}, \theta_{x_1}, \theta_{y_2}, \theta_{\varsigma_3}\}^T$ express as nodal displacement vector and [*Ni*] denotes the nodal interpolation function.

Governing equation

By using Hamilton's principle, the final form of the governing equation for vibration analysis of sandwich composite plate is expressed as:

$$\lambda\int_{t_1}^{t_2}(V-U)=0 \quad (4)$$

where 'V' indicates kinetic energy and 'U' shows the strain energy.

Governing equation may also be expressed for the vibration analysis as:

$$[M]\ddot{\lambda}+[K]\lambda=0 \quad (5)$$

where, $\ddot{\lambda}$ represents the acceleration and λ denotes the displacement.

Now for the free vibration, the fundamental frequency can be found by the equation,

$$([K]-\omega^2[M])\Delta=0 \quad (6)$$

where ω represents natural frequency and Δ is the corresponding Eigen-vector.

In this study, these support conditions are used.

Simply Supported condition (S):

$$\bar{v}=\bar{w}=\theta_{y_2}=\varsigma_3=0 \text{ at } x=0 \text{ and } a$$
$$\bar{u}=\bar{w}=\theta_{x_1}=\varsigma_3=0 \text{ at } y=0 \text{ and } b$$

Fully clamped condition (C):

$$\bar{u} = \bar{v} = \bar{w} = \theta_{x_1} = \theta_{y_2} = \varsigma_3 = 0$$
at $x = 0$ and a, $y = 0$ and b

Free end condition (F):

$$\bar{u} \neq \bar{v} \neq \bar{w} \neq \theta_{x_1} \neq \theta_{y_2} \neq \varsigma_3 \neq 0$$
at $x = 0$ and l, $y = 0$ and b

Table 1. Material characteristics of a sandwich composite panel. [13]

Properties	Material I	Material II
E_1 (*Pa*)	24.51×10^9	0.104×10^9
E_2 (*Pa*)	7.77×10^9	0.104×10^9
$G_{12} = G_{13}$ (*Pa*)	3.34×10^9	0.05×10^9
G_{23} (*Pa*)	3.34×10^9	0.05×10^9
ν_{12}	0.0078	0.32
ρ (Kg/m^3)	1800	130

RESULTS AND DISCUSSION

The eigenfrequency behavior of the square sandwich composite panel with predefine hole are examined in the ANSYS environment by applying the FE steps. The essential validation study of the current model has been done before implementing the code for further numerical investigation. Table 1 contains the material properties used for validation and further investigation. After the validation study, it is possible to calculate the frequency responses of sandwich panels including the impact of numerous factors like cutout ratios, cutout shape and mode shapes.

Validation Study

In this study, the constructed FE model has been validated by comparing its results to those of previously published data. For that, a square sandwich plate (0º/90º/core/0º/90º) with an aspect ratio (a/h=10) and core-face thickness ratio (h_c/h_f=16) is examined under a variety of constraint conditions. Table 1 shows materials parameters as Materials I and Material II, which are employed for the face skin and core of the sandwich composite, respectively. The frequency responses are converted into non-dimensional form Ω using $\Omega = \omega\left(a^2/h\right)\left(\sqrt{\rho_c/E_{2c}}\right)$ and listed in Table 2.

Table 2. The frequency responses of a square sandwich plate under various boundary conditions.

Boundary Condition	Method	Mode				
		1	2	3	4	5
CCCC	Present [ANSYS]	18.939	31.285	31.285	40.618	46.641
	Hachemi et al. [13]	19.431	30.932	31.742	40.425	45.372
SSSS	Present [ANSYS]	14.486	29.135	29.135	36.091	36.092
	Hachemi et al. [13]	15.076	28.528	29.299	38.248	40.307
CSCS	Present [ANSYS]	17.100	30.453	30.886	35.836	40.369
	Hachemi et al.[13]	17.159	30.003	30.073	39.251	40.307
CFCF	Present [ANSYS]	13.389	14.975	26.005	28.118	30.302
	Hachemi et al. [13]	13.317	14.887	26.161	27.142	29.378
CFFF	Present [ANSYS]	3.491	6.201	13.274	15.598	19.435
	Hachemi et al. [13]	3.809	6.411	15.406	15.434	19.279

New Numerical Illustration

The validation investigation shows that the currently developed simulation model can properly predict the model responses of the square sandwich plate with cutout. Now, the model responses have been computed for the sandwich structure including various design factors like cutout ratio, cutout shape, and mode shape to highlight the significance of the computational model. At first, one or more factors are changed while the others stay the same.

Influence of cutout ratio on frequency response of sandwich panel. In this example, the flat sandwich panel (l/b=1) is taken for the vibration analysis with the core-to-face thickness ratio (h_c/h_f=16), aspect ratio (a/h=10), fiber orientation 0º/90º/core/0º/90º under fully clamped boundary condition (CCCC). Four alternative square cutout ratios (c/c'= 0.2, 0.4, 0.6, and 0.8) have been used to analyse the vibration responses of the sandwich panel. The cutout ratio may be defined the ratio of the cutout area (c) to the panel area (c'). According to Fig.2, the frequency value increases monotonically with increasing cutout ratios in all modes. It may happen due to the rigidity of the developed composite plate increasing by losses of mass as increasing of cutout ratio. Fig. 3 shows the first five mode shapes that are generated for the current investigation in a ς-direction deformation.

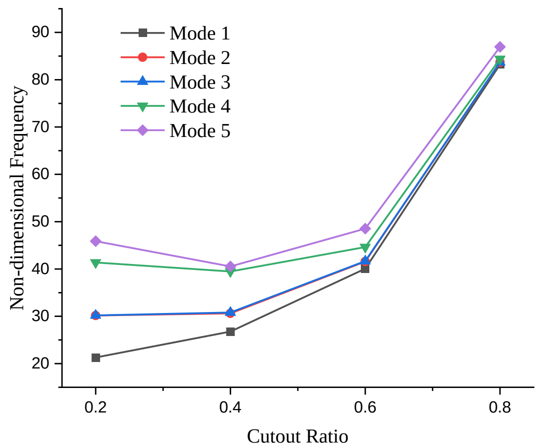

Figure 2: Impact of cutout ratio on eigen-frequency responses for a sandwich plate.

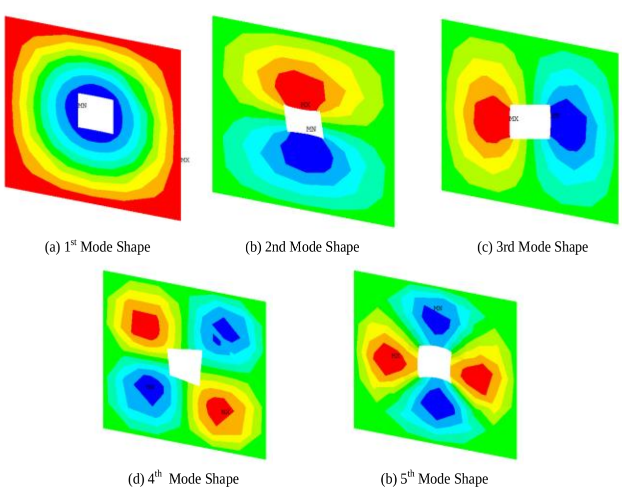

Figure 3: First five mode shapes of a sandwich flat panel with square cutout.

Influence of cutout shape on frequency response of sandwich panel. This section focused on the impact of cutout shape on the model analysis for a square sandwich composite panel (0º/45º/core/0º/45º) with core-face thickness ratio (h_c/h_f=18), aspect ratio (a/h=40) subjected to fully clamped boundary condition. Fig. 4 shows four types of cutouts for the model analysis: a rectangle, a square, an ellipse and a circle. All of them have the same area of 0.16. Table 3 demonstrates the effect of various cutout shapes on the frequency characteristics of the sandwich panel, and it can be observed that the circular cutout shape achieves the highest frequency while the rectangular cutout shape achieves the lowest frequency in the first mode. But in higher mode, rectangular cutout shape shows a higher natural frequency and square cutout shape shows the lowest. In the first mode, square and elliptical cutouts have roughly similar natural frequencies.

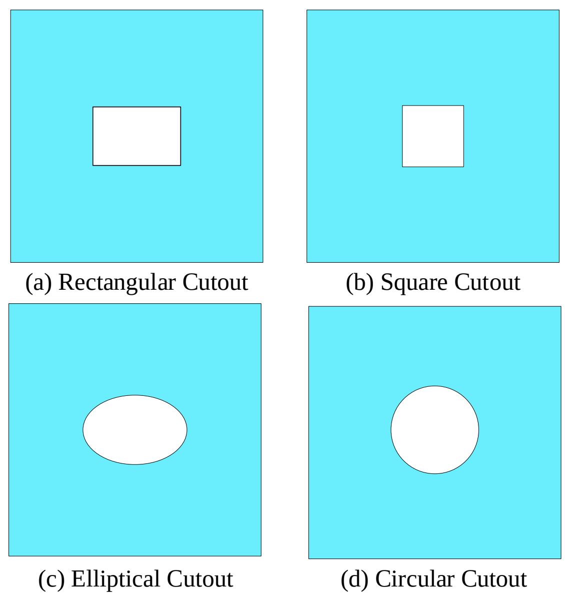

Figure 4: Various cutout shapes in a sandwich flat panel.

Table 3. The natural frequency responses of a square sandwich composite plate under various cutout shapes.

Cutout	Mode				
	1	2	3	4	5
Rectangular	42.966	43.0344	85.503	85.130	131.854
Square	54.165	63.866	71.054	96.321	97.305
Elliptical	54.446	56.827	78.485	94.332	112.216
Circular	55.005	65.688	73.065	93.773	108.047

Influence of the core-face thickness ratio on frequency response of sandwich panel. In this section, the impact of various core-face sheet thickness ratios on the dynamic behavior of sandwich structure with circular cutout has been investigated under fully clamped conditions. The sandwich panel (0º/60º/core/60º/0º) taken geometrical parameters as h_c/h_f=4,8,12,16, a/h=50 and l/b= 1. The computed responses for the model analysis of said panel are illustrated in Fig.5. From the given figure, it can be seen that the panel shows a higher frequency response which has the lowest core-face thickness ratio (h_c/h_f=4) and vice-versa. This is due to the core part. The core is made of a lower-density material, reducing the overall stiffness of the structure, as stated in the above section.

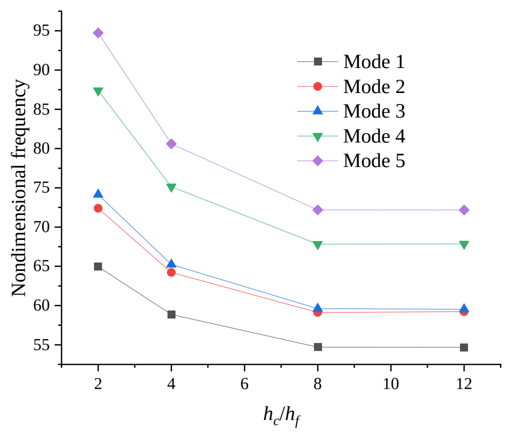

Figure 5: Impact of various core-face thickness ratios on vibration response for a sandwich panel.

Influence of various edge restrictions on frequency response of sandwich panel. In this section, the impact of various end conditions on the frequency characteristics of sandwich flat panels with square cutout has been examined. The sandwich panel (0º/45º/core/45º/0º) taken geometrical parameters as h_c/h_f=10, a/h=60 and l/b= 1. The computed responses for the model analysis of said panel are illustrated in Fig.6. From the plotted figure, it can be seen that the panel shows a frequency response in the following order: CCCC>CSCS>CFCF>SSSS>SSSS. This trend is showing due to the restriction of motion of the panel.

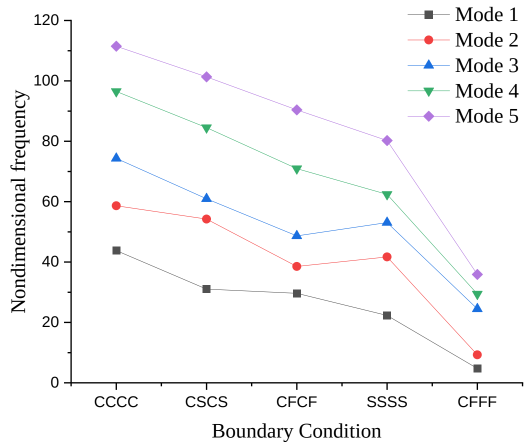

Figure 6: Impact of various end conditions on vibration response for a sandwich panel.

CONCLUSIONS

The frequency characteristics of square sandwich flat panels with cutouts are explored in this present body of work, with special attention to the geometry and shape of the cutouts. The numerical investigation has been carried out by the lower-order theory in combination with FE method. In order to calculate the frequency responses, the sandwich flat panel with the cutout is simulated in the ANSYS programme by utilizing code written in the ANSYS parametric design language (APDL). For the validation purpose, the authors also compare the simulated frequency results with the published values. Finally, the existing simulation model has been used to numerically solve some new examples to investigate the frequency response on the developed flat panel including the effect of different cutout parameters. According to the parametric study, the frequencies of the developed sandwich plate increase with increase in cutout ratio, and maximum and minimum frequencies were also observed for circular and rectangular cutout shapes, respectively. Likewise, the maximum frequency has been recorded for the minimum core-face thickness ratio and fully clamped end conditions.

REFERENCES

[1] Y. jing Wang, Z. jia Zhang, X. min Xue, and L. Zhang, "Free vibration analysis of composite sandwich panels with hierarchical honeycomb sandwich core," *Thin-Walled Structures*, vol. 145, no. November 2018, p. 106425, 2019, doi: 10.1016/j.tws.2019.106425.

[2] A. K. Nayak, S. S. J. Moy, and R. A. Shenoi, "Free vibration analysis of composite sandwich plates based on Reddy ' s higher-order theory," vol. 33, pp. 505–519, 2002.

[3] S. M. N. Serdoun and S. M. Hamza Cherif, "Free vibration analysis of composite and sandwich plates by alternative hierarchical finite element method based on Reddy's C1 HSDT," *Journal of Sandwich Structures and Materials*, vol. 18, no. 4, pp. 501–528, 2016, doi: 10.1177/1099636215603033.

[4] M. Meunier and R. A. Shenoi, "Free vibration analysis of composite sandwich plates," *Proc Inst Mech Eng C J Mech Eng Sci*, vol. 213, no. 7, pp. 715–724, 1999, doi: 10.1177/095440629921300707.

[5] D. Elmalich and O. Rabinovitch, "A high-order finite element for dynamic analysis of soft-core sandwich plates," *Journal of Sandwich Structures and Materials*, vol. 14, no. 5, pp. 525–555, 2012, doi: 10.1177/1099636212449841.

[6] V. N. Burlayenko and T. Sadowski, "A numerical study of the dynamic response of sandwich plates initially damaged by low-velocity impact," *Comput Mater Sci*, vol. 52, no. 1, pp. 212–216, 2012, doi: 10.1016/j.commatsci.2011.01.009.

[7] T. Kant and K. Swaminathan, "Analytical solutions for free vibration of laminated composite and sandwich plates based on a higher-order refined theory," *Compos Struct*, vol. 53, no. 1, pp. 73–85, 2001, doi: 10.1016/S0263-8223(00)00180-X.

[8] S. R. Farsani, A. Ramian, R.-A. Jafari-Talookolaei, P. S. Valvo, and M. Abedi, "Free vibration analysis of rectangular sandwich plates with compressible core and various boundary conditions," *Journal of Sandwich Structures & Materials*, vol. 23, no. 8, pp. 4077–4106, Nov. 2021, doi: 10.1177/1099636220979276.

[9] H. Sekine, H. Shirahata, and M. Matsuda, "Vibration Analysis of Composite Sand-," pp. 557–566, 2005.

[10] P. Senthilkumaran, R. Venkatachalam, and K. V. Raja, "Vibration Analysis of a multi core sandwich composite beam with cutouts — A critical investigation Vibration Analysis of a multi core sandwich composite beam with cutouts — A critical investigation," 2021.

[11] J. N. Reddy, "Large amplitude flexural vibration of layered composite plates with cutouts," *J Sound Vib*, vol. 83, no. 1, pp. 1–10, 1982, doi: 10.1016/S0022-460X(82)80071-0.

[12] L. Hadji and M. Avcar, "Free Vibration Analysis of FG Porous Sandwich Plates under Various Boundary Conditions," *Journal of Applied and Computational Mechanics*, vol. 7, no. 2, pp. 505–519, 2021, doi: 10.22055/jacm.2020.35328.2628.

[13] M. Hachemi, "Free vibration analysis of composite laminated and sandwich plate with circular cutout," 2018, doi: 10.1177/1099636218811393.