Dynamic analysis of laminated composite sandwich plates with a circular hole

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Abstract. The current manuscript pacts the finite element investigation of the modal characteristics of the laminated composite sandwich (LCS) plate containing a circular hole. A series of simulations are executed to examine the influence of fiber orientations, edge constraints, the ratio of the thickness of core to face sheet, the radius of hole, and location of the hole on the system on the frequency response of the system. The analysis are carried out using ANSYS simulation tool

Keywords: Finite element analysis, laminated composite sandwich plate, plate with the hole

1. Introduction

The LCS materials are comprehensively being cast off in civil, aerospace, automotive industries, etc. The sandwich structures are primarily used for engineering structures experiencing transverse loads. The moment of inertia of the structure is directly proportional to the cube of the depth of the member. The structures under bending loads experience maximum stresses at the outer surfaces of the structural members. The sandwich structure addresses these problems effectively as they are made of soft & thick core to provide inertia (also reduce the weight), and strong & thin face sheets withstand the stresses. Laminated composite sandwich (LCS) structures are prepared by joining the laminated composite mats with the core material. There are so many core materials which can be used to make sandwich laminated plate such as Polyurethane foam, balsa wood, cork, Polyethylene Terephthalate (PET) foams, viscoelastic cores, etc. The materials used in industrial structures are anticipated to work in line with the sub-assembly modules. The composite structures are usually riveted to assemble with other preceding components, which involve drilling the circular holes into the material. The composite materials tend to delaminate on machining, and this may, in turn, initiate the localized failure mechanism. Hence, there is anatrocious requirement to investigate and comprehend the LCSs with unmethodical geometry.

Yuan et al. [1] executed analysis of sandwich plates with laminated faces. A uniquely developed finite element (FE) model was used to foretell the frequencies of the LCS structure. Rao et al. [2] examined the dynamic response of the LCS plates using mixed theory. Further, natural frequency, the magnitude of stress, displacement, and the eigenvector for LCS plates were investigated. Mishra et al. [3] considered various boundary conditions to investigate the frequency response of the woven fiber composite plate. The investigation was concerned with the free vibration analysis of industry-
driven woven fiberglass/epoxy composites plates with different boundary conditions, including free-free cases. Kallannavar and Kattimani [4-6] investigated the modal response of the sandwich plates operating in challenging environmental conditions. The frequency response of the composite plate containing circular cut-out was also reported. Mishra and Sahu [7] numerically and experimentally inspected the frequency response of the woven fiber composite plate for various edge constraints. Nikhil et al. [8] carried out a dynamic simulation of hybrid laminated and sandwich plates using ANSYS simulation tool. Gburi et al. [9] performed simulations on the isotropic skew plate using ANSYS APDL module for various boundary conditions.

In this paper, the frequency responses of LCS plates with a hole are reported. From the literature survey, it can be noted that the work presenting the parametric investigation, such as the influence of fiber alignment, boundary constraints, aspect ratio, and material type, on the fundamental frequency of LCS plates are presented by many researchers[10-20]. Whereas the works about the vibration analysis of LCS plates contained circular holes are sparse. Hence, an effort is made to scrutinize the dynamic conduct of LCS plates with a hole.

2. Finite Element Analysis
The FE simulation of the LCS plate containing a hole is performed. The analysis is performed utilizing the Ansys simulating tool using solid-shell 3D finite strain 190. The Block Lanczos method was implemented for modes extraction. The dimensions of the laminated composite plate are 7.6 cm x 7.6 cm, and a laminated sandwich plate containing a hole is 15.2 cm x 7.6 cm, and the diameter of the hole is 4 cm. The laminated composite plate is considered to have 8 layers, with each film 0.013 cm thick. Different fiber alignments are considered for the analysis of the LCS plate. Aluminum core of thickness 0.052 cm thickness is sandwiched between graphite-epoxy laminates of 0.013 cm thickness each.

The laminated composite plate and LCS plate with a hole were analyzed for edge constraints clamped at one end, i.e., cantilever (CFFF) and all side clamped (CCCC), as shown in Figure 1. Table 1 lists the material properties considered for the analysis.

![Figure 1](image.png)

**Figure 1.** Pictorial depiction of boundary constraints used for the simulations (a) CFFF (b) CCCC.

| Properties                  | Units  | Graphite-Epoxy | Aluminum |
|-----------------------------|--------|----------------|----------|
| Density (ρ)                 | Kg/m³  | 1500           | 2689.8   |
| Linear Modulus (Eₓ)         | GPa    | 128            | 68       |
| Linear Modulus (Eᵧ, Eẑ)     | GPa    | 11             | --       |
| Poisson’s Ratios (vₓᵧ, vₓẑ, vᵧẑ) | 0.25   | 0.34           | --       |
| Shear Modulus (Gₓᵧ)        | GPa    | 4.48           | --       |
| Shear Modulus (Gₓẑ, Gᵧẑ)   | GPa    | 1.53           | --       |

3. Outcomes and Disclosure
The dynamic analysis was performed for the isotropic Aluminium composite plate, Graphite-Epoxy laminated composite, and Graphite-Epoxy laminated sandwich plate with aluminium core under CFFF boundary condition. The fundamental frequencies obtained from FE analysis are compared with the results of Crawley [18] and Kallannavar et al. [5], as shown in Table 2 and Table 3. Additionally, the simulations are carried out to appreciate the effect of edge constraints and ply orientation of the face sheet on the modal characteristics of the sandwich plate with a center hole.

### Table 2. Natural frequency of 7.6 cm X 7.6 cm one end clamped [CFFF] plate

| Orientations     | Mode | Crawley [18] | Kallannavar et al. [5] | Present |
|------------------|------|--------------|------------------------|---------|
| Aluminium        | 1    | 151.9        | 153.2                  | 152.81  |
|                  | 2    | 369.7        | 368.9                  | 366.49  |
|                  | 3    | 937.7        | 962.1                  | 928.93  |
|                  | 1    | 261.9        | 261.2                  | 260.66  |
| [0°/0°/30°/-30°]s| 2    | 363.5        | 361.1                  | 359.5   |
|                  | 3    | 761.8        | 764.2                  | 750.99  |
|                  | 1    | 224.3        | 223.7                  | 223.11  |
| [0°/45°/-45°/90°]s| 2    | 421.8        | 419.8                  | 416.06  |
|                  | 3    | 1012.0       | 1017.7                 | 995.71  |
|                  | 1    | 138.9        | 137.9                  | 136.83  |
| [45°/-45°/-45°/45°]s| 2    | 499.5        | 496.8                  | 488.01  |
|                  | 3    | 805.0        | 813.8                  | 779.73  |

### Table 3. Natural frequency of 15.2 cm X 7.6 cm one end is clamped [CFFF] sandwich plate

| Orientation                  | Mode | Kallannavar et al. [5] | Present |
|------------------------------|------|------------------------|---------|
| [0°/0°/core/0°/0°]           | 1    | 242.2                  | 240.21  |
|                              | 2    | 354.5                  | 355.91  |
|                              | 3    | 448.3                  | 450.30  |
|                              | 1    | 278.3                  | 278.28  |
| [45°/core/45°]               | 2    | 368.9                  | 365.97  |
|                              | 3    | 528.9                  | 530.11  |
|                              | 1    | 348.3                  | 348.91  |
| [90°/core/90°]               | 2    | 398.9                  | 396.91  |
|                              | 3    | 509.5                  | 515.06  |

The LCS structures are modelled using Graphite-Epoxy face sheets and the core of Aluminum. The face sheets of thickness 0.026 cm each and the core thickness of 0.052 cm were considered for the analysis. The face sheets were made of 2 layers having a thickness of 0.013 cm. The FE analysis obtained the frequencies of the LCS plate with a hole for two edge constraints, and different ply orientations of are recorded in Table 4.

### Table 4. Fundamental frequency of 1.52 cm X 7.6 cm sandwich plate

| Orientation                  | Mode | CFFF | CCC |
|------------------------------|------|------|-----|
| [0°/0°/core/0°/0°]           | 1    | 37.99| 307.30|
|                              | 2    | 56.08| 328.02|
|                              | 3    | 75.08| 614.28|
|                              | 1    | 35.59| 318.88|
| [45°/45°/core/45°/45°]       | 2    | 56.74| 349.61|
|                              | 3    | 71.17| 633.04|
|                              | 1    | 38.57| 361.60|
| [90°/90°/core/90°/90°]       | 2    | 54.12| 378.93|
From Table 4, the ply orientation of [90/90/core/90/90] has a greater fundamental frequency for both end constraints (i.e., CFFF and CCCC).

3.1. Space considerations Influence of $t_c/t_f$ Ratio

The investigation was drawn out to explore the influence of the $t_c/t_f$ ratio on the natural frequency of the LCS plate with a central hole for different edge constraints. Fundamental frequencies of LCS plate for varying $t_c/t_f$ ratio were studied by considering the $t_f$ (0.52 mm) as a constant dimension. The results were listed in below Table 5.

| Orientation | Mode | CFFF | CCCC |
|-------------|------|------|------|
| [0°/0°/core/0°/0°] | 1 | 37.44 | 324.48 |
| | 2 | 55.77 | 343.91 |
| | 3 | 74.89 | 636.35 |
| | 1 | 37.23 | 325.37 |
| | 2 | 55.61 | 345.37 |
| | 3 | 74.47 | 637.02 |
| | 1 | 37.15 | 326.21 |
| | 2 | 55.54 | 345.88 |
| | 3 | 74.30 | 637.16 |
| | 1 | 37.10 | 326.42 |
| | 2 | 55.51 | 346.13 |
| | 3 | 74.21 | 638.14 |

From Table 5, it is apparent that for all modes, the variation in frequency for the different $t_c/t_f$ ratios is minimal for both boundary conditions CFFF and CCCC. The natural frequency has higher for all modes to CCCC as compared to the CFFF boundary condition.

3.2. Influence of Size of the Circular Hole

The simulations were also executed to explore the influence of varying radius of hole, i.e., 0.01 m, 0.015 m, 0.020 m, and 0.025 m, on the natural frequency of LCS plate. The frequency values obtained from FE analysis for different boundary conditions and ply orientation [0°/0°/core/0°/0°] have been listed below in Table 6.

| Mode | CFFF | CCCC |
|------|------|------|
| 1 | 38.34 | 280.09 |
| 2 | 58.96 | 342.22 |
| 3 | 76.66 | 518.60 |

**Table 5.** The fundamental frequency of 15.2 cm X 7.6 cm LCS plate with lay-up sequence [0°/0°/core/0°/0°] and boundary condition.

**Table 6.** Fundamental frequency of 15.2 cm X 7.6 cm LCS plate with a hole of varying and boundary conditions radius for [0°/0°/core/0°/0°] lay-up sequence.
4. compared to the CFFF boundary condition. The frequency is higher for the CCCC end constraint as compared to the fundamental mode. From Table 7, it can be perceived that the locality of the hole has a predominant effect on the higher fundamental frequencies of LCS plate for different locations of holes.

The analysis were also conducted to understand the influence of the location of the hole on the frequency of LCS plate with a hole. The rectangular plate with hole of dimension 15.2 m x 7.6 cm and diameter 4 cm at different location with fibre orientation [0°/0°/core/0°/0°]. The coordinates of position for the center of hole considered for analysis are Left: (2.28 m, 3.8 m), Bottom: (7.6 cm, 3 cm), Right: (12.92 cm, 3.8 cm), and Top: (7.6 cm, 4.8 cm) as shown in below fig. 3. Table 7 lists the frequency of LCS plate with a hole.

| Mode  | CFFF | CCCC |
|-------|------|------|
| 1     | 35.98| 263.86|
| 2     | 56.48| 361.22|
| 3     | 71.95| 527.45|
| 1     | 36.05| 287.98|
| 2     | 56.09| 331.46|
| 3     | 72.08| 534.05|
| 1     | 35.28| 262.18|
| 2     | 56.30| 353.04|
| 3     | 70.42| 524.12|
| 1     | 37.84| 287.46|
| 2     | 54.26| 330.19|
| 3     | 75.67| 546.76|

From Table 7, it is obvious that the variation in the frequency values increases with an increase in the radius of the hole for both end constraints. As the radius of the hole cut-out from the LCS plate increases the overall mass of the plate and hence the trend. It is apparent that the natural frequency has a higher magnitude for all modes to CCCC edge constraints as compared to CFFF.

3.3. Effect of Location of Hole
The analysis were also conducted to understand the influence of the location of the hole on the frequency of LCS plate with a hole. The rectangular plate with hole of dimension 15.2 m x 7.6 cm and diameter 4 cm at different location with fibre orientation [0°/0°/core/0°/0°]. The coordinates of position for the center of hole considered for analysis are Left: (2.28 m, 3.8 m), Bottom: (7.6 cm, 3 cm), Right: (12.92 cm, 3.8 cm), and Top: (7.6 cm, 4.8 cm) as shown in below fig. 3. Table 7 lists the fundamental frequencies of LCS plate for different locations of holes.

Figure 3. Symbolic representation of the location of a circular hole in the rectangular LCS plate with hole.

Table 7. Fundamental frequency of 15.2 cm X 7.6 cm LCS plate with hole by varying hole position with lay-up sequence [0°/core/0°] and edge constraints

| Orientation | Hole Position | Mode | CFFF | CCCC |
|-------------|--------------|------|------|------|
| Left        | 1            | 35.98| 263.86|
|             | 2            | 56.48| 361.22|
|             | 3            | 71.95| 527.45|
|             | 1            | 36.05| 287.98|
| Bottom      | 2            | 56.09| 331.46|
|             | 3            | 72.08| 534.05|
|             | 1            | 35.28| 262.18|
| Right       | 2            | 56.30| 353.04|
|             | 3            | 70.42| 524.12|
|             | 1            | 37.84| 287.46|
| Top         | 2            | 54.26| 330.19|
|             | 3            | 75.67| 546.76|

From Table 7, it can be perceived that the locality of the hole has a predominant effect on the higher modes as compared to the fundamental mode. The frequency is higher for the CCCC end constraint as compared to the CFFF boundary condition.

4. Conclusion
From current study the following conclusion points can be noted:

- The ply orientation of [90/90/core/90/90] has a higher frequency for both boundary conditions CFFF and CCCC.
- The plate with t/c ratio of 10 has a maximum frequency for the CFFF boundary condition, and a thickness ratio value of 100 has a maximum fundamental frequency for CCCC boundary conditions.
- The radius of the hole of 0.025 m has a maximum frequency for both boundary conditions CFFF and CCCC as compared to other radii of the hole.
- The deviation in frequency values for various locations of the hole is minimal for both boundary conditions CFFF and CCCC.

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