3PC SOLVER004

Free Vibration Analysis of Simply-Supported Anisotropic Laminated Composite Plates

1/30/2023

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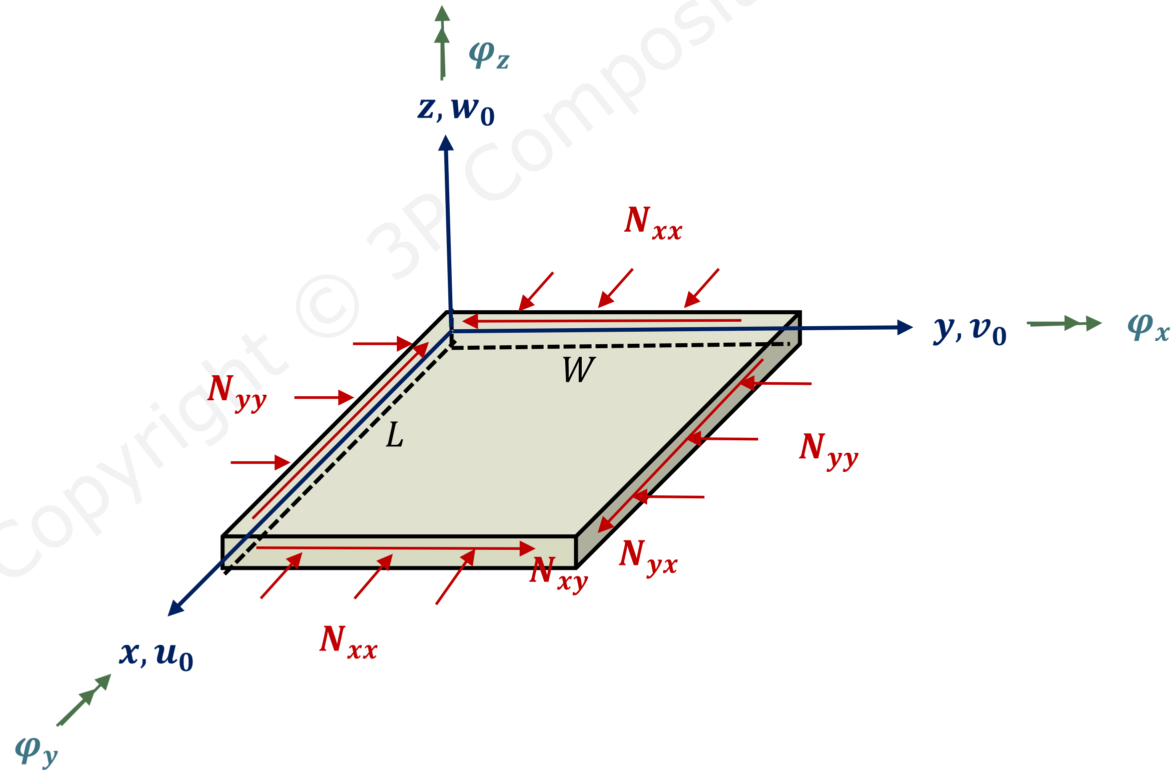
Contents: 3pcsolver004

Overview

- 3pcsolver004 performs free vibration analysis of simply-supported fully anisotropic composite laminates. Simply-supported boundary condition is most widely used in the analysis of plates and shells. Natural (or fundamental) frequencies and the associated mode shapes for fully anisotropic composite laminates are computed by the solver. Furthermore, 3pcsolver004 solver can include the effects of in-plane mechanical and hygrothermal tension/compression and/or shear edge loads on the natural frequencies of vibration for fully anisotropic simply-supported composite laminated plates



Applications

- Free vibration analysis performed by 3pcsolver004 solver is applicable to laminates built-up (or fabricated) from a LAMINA that
  - has any kind of FIBER such as boron, carbon, graphite, glass, Kevlar, Aramid, polyester, natural fibers, etc.,
  - is in any type of broad form such as short and long continuous, unidirectional, bi-directional 2D textile weaves like plain weave, twill and harness, biaxial and triaxial braids, chopped random fibers, non-crimp, nonwoven fabrics, etc.
  - Is impregnated with any RESIN/MATRIX, thermoset or thermoplastic systems such as epoxy, polyester, vinyl ester, polyurethane, phenolic, cyanate ester, bis-maleimide, polyimides, benzoxazine, Acrylic, ABS, Polylactic acid PLA, Polybenzimidazole PBI, Polyether sulfone PES, Polyoxymethylene POM, Polyether ether ketone PEEK, Polyetherimide PEI, Polyphenylene oxide PPO, Polyphenylene sulfide PPS, Polystyrene PS, Polypropylene PP, Polyvinyl chloride PVC, Teflon PTFE, etc.
  - is cured using any MANUFACTURING PROCESS such as Autoclave, Resin Transfer Molding like VARTM, SQRTM, RIM, SRIM, Filament Winding, Pultrusion, Compression Molding, Wet-lay up, etc.

- The analysis is equally applicable to Hybrid Laminates manufactured from a single or multiple types of lamina materials and/or ply broad forms or fiber types or single or multiple materials systems or their combinations

Theoretical Background

- **3pcsolver004** solver is based on First-Order Shear Deformation Laminated Plate Theory (Mindlin Type). Spatial distributions of displacements $\boldsymbol{u}$, $\boldsymbol{v}$ and $\boldsymbol{w}$, and rotations $\boldsymbol{\varphi_x}$ and $\boldsymbol{\varphi_y}$ of the plate's reference surface are assumed using double Fourier series satisfying the kinematic boundary conditions at all four simply-supported edges of the laminated plate exactly. Neglecting the rotatory inertia terms, using Hamilton's principle and Ritz analysis procedure, a highly coupled system of algebraic equations for free vibration analyses of fully anisotropic laminated plate is obtained as shown below:

$$\begin{bmatrix} K_{11}-m_p\omega_{mn}^2 & K_{12} & 0 & K_{14} & K_{15} \\ K_{21} & K_{22}-m_p\omega_{mn}^2 & 0 & K_{24} & K_{25} \\ 0 & 0 & K_{33}-m_p\omega_{mn}^2 & K_{34} & K_{35} \\ K_{14} & K_{42} & K_{43} & K_{44} & K_{45} \\ K_{51} & K_{25} & K_{53} & K_{54} & K_{55} \end{bmatrix} \begin{Bmatrix} u_{mn} \\ v_{mn} \\ w_{mn} \\ \varphi_{xmn} \\ \varphi_{ymn} \end{Bmatrix} e^{i\omega t} = \begin{Bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{Bmatrix} e^{i\omega t}$$

- In the equations above, K_{ij} are the stiffness terms containing the laminate A_{ij}, B_{ij} and D_{ij} and m_p is the mass term. u_{mn}, v_{mn} and w_{mn} are the unknown coefficients of displacements, and φ_{xmn} and φ_{ymn} are the unknown coefficients of rotations of the laminated plate. ω_{mn} is the circular or angular frequency (radian/second) of vibration. Effects of total applied edge loads from mechanical and hydrothermal loadings are contained in the K_{33} stiffness term

Theoretical Background

- Hygrothermal effects can be accounted for the given difference in temperature ΔT and difference in moisture content ΔC. Laminated plate theory can be used to compute thermal force resultants N_{xx}^{T}, N_{yy}^{T} & N_{xy}^{T} and/or moisture force resultants N_{xx}^{M}, N_{yy}^{M} & N_{xy}^{M} as shown below

$$\begin{Bmatrix} N_{xx}^{T\,or\,M} \\ N_{yy}^{T\,or\,M} \\ N_{xy}^{T\,or\,M} \end{Bmatrix} = [A'] \begin{Bmatrix} \varepsilon_{xx}^{T\,or\,M} \\ \varepsilon_{yy}^{T\,or\,M} \\ \gamma_{xy}^{T\,or\,M} \end{Bmatrix} \qquad A' = -BD^{-1}B^{T} + A$$

- The total applied in-plane edge loads are then obtained as summation of mechanical and hydrothermal force resultants as

$$\begin{Bmatrix} N_{xx}^{Total} \\ N_{yy}^{Total} \\ N_{xy}^{Total} \end{Bmatrix} = \begin{Bmatrix} N_{xx}^{T} \\ N_{yy}^{T} \\ N_{xy}^{T} \end{Bmatrix} + \begin{Bmatrix} N_{xx}^{M} \\ N_{yy}^{M} \\ N_{xy}^{M} \end{Bmatrix} + \begin{Bmatrix} N_{xx} \\ N_{yy} \\ N_{xy} \end{Bmatrix}$$

- Note that the total applied in-plane edge loads should be around 30% of the corresponding critical laminated plate buckling load

Theoretical Background

- The determinant of the system of $5M \times 5N$ equations for the Eigen-value problem derived above is set to zero to obtain angular frequencies ω_{mn} for simply-supported fully anisotropic plates including the effects of combinations of applied compression/tension and/or edge shear loads

$$\begin{vmatrix} K_{11} - m_p\omega_{mn}^2 & K_{12} & 0 & K_{14} & K_{15} \\ K_{21} & K_{22} - m_p\omega_{mn}^2 & 0 & K_{24} & K_{25} \\ 0 & 0 & K_{33} - m_p\omega_{mn}^2 & K_{34} & K_{35} \\ K_{14} & K_{42} & K_{43} & K_{44} & K_{45} \\ K_{51} & K_{25} & K_{53} & K_{54} & K_{55} \end{vmatrix} = 0$$

- Solution to the Eigen-value problem is obtained for truncated Fourier series using $m = 1,2,..,M$ terms in the x –direction and $n = 1,2,..,N$ terms in the y –direction. Without loss of generality, $M = N$ is assumed for the solution. Natural frequencies of vibration can be obtained as $f_{mn} = \frac{\omega_{mn}}{2\pi}$. Vibration mode shapes for each natural frequency f_{mn} can be obtained by substituting ω_{mn} in the system of equations given on the previous slide and solving for the displacements and rotations of the laminated plate

- Given the lamina/ply material properties, laminate stack-up and its length and width dimensions, 3pcsolver004 solver calculates natural frequencies of vibration and associated mode shapes for an anisotropic laminated plate

Theoretical Background

- The 3pcsolver004 is a unique solver which is based on FSDT of laminated plates, employs a closed-form Ritz solution procedure, considers the fully anisotropic laminate effects, and obtains natural frequencies of vibration for laminated composite plates with or without the effects of in plane edge loads. All types of laminate coupling terms represented by the non-zero A_{i6}, B_{ij} and D_{i6} ($i = 1{,}2$, and $j = 1{,}2{,}6$) are included in the free vibration analysis of laminated composite plates. Most closed-form analyses neglect these coupling effects due to the complexity in deriving the system of equations, and hence, assume the laminated plates as being specially orthotropic (i.e. $A_{i6} = B_{ij} = D_{i6} = 0, i = 1{,}2\ , j = 1{,}2{,}6$)

- Numerous examples are solved using **3pcsolver004**, and results are compared with those (i) obtained from standard commercially available finite element analysis software, and (ii) available in open literature. Many types of material systems, ply orientations, laminate stack ups, laminate dimensions, and types of in-plane edge loads are considered to check the accuracy of the solver. Excellent correlations are obtained in all cases. Numerical examples highlight the adverse effects of various types of laminate stiffness couplings on the natural frequencies and mode shapes of anisotropic laminated composite plates

- Details of the theoretical approach along with numerous verification and application examples are available in the training module **3pcmodule004**

Inputs

- All inputs should be in consistent units. Use either (N, m, Pa) OR (N, mm, MPa) or (lbs, in, Psi) consistently. Inputs in scientific notation (0.0+e) are acceptable

- Input process is intuitive and uses the following logical order:

  - Materials
  - Plies / Laminae
  - Laminates
  - Panels
  - Loads
  - Analysis Options

Inputs: Materials

❖ Material Properties:

In the SI system, MPa and mm or Pa and m, and in the US system Msi and in are used to input the orthotropic lamina Moduli E_1, E_2, G_{12}, G_{13} and G_{23}. ν_{12} is major Poison's ratio. ρ is material density in Kg/m^3 or lb/in^3. Multiple lamina types and lamina materials can be input by simply clicking the '+' sign on the extreme right. Based on the type of analyses selected, the required material inputs for an orthotopic Lamina can vary as shown below:

Materials

ID	E_1	E_2	G_{12}	G_{23}	G_{13}	ν_{12}	ρ		
aiaa-2009	18000000	1600000	870000	640000	870000	0.3	0.000149	+	–

Inputs: Plies

❖ Plies/Laminae:

Types of plies in a laminate are required as input. Each ply type is defined by its angle (or orientation) in degrees, material type and the thickness. Material of a ply/lamina can be selected from a predefined list of materials that are input in the Material Properties Section above. The thickness of the ply or lamina is in mm or m in the SI system or inch in the US system. Multiple ply or lamina types can be input by simply clicking the '+' sign on the extreme right. The required ply/lamina type inputs with few examples are shown below:

Plies

ID	Angle (deg)	Material	Thickness		
1	0	aiaa-2009	0.00525	+	−
2	90	aiaa-2009	0.00525	+	−
3	45	aiaa-2009	0.00525	+	−
4	-45	aiaa-2009	0.00525	+	−

Inputs: Laminates

❖ Laminates:

Multiple laminates can be quickly created by defining their stacking sequences using the plies defined in the previous step. Laminate Offset is fixed at middle (default). Hybrid laminates can be defined using different ply and material combinations established in the previous steps. Additional laminates can be added by simply clicking the '+' sign on the extreme right. A few examples of laminates and their inputs are shown below:

Laminates

ID	Stacking Sequence	Stacking Sequence (Angle)	Offset		
1	3,4,3,4,4,3,4,3	45,-45,45,-45,-45,45	Middle	+	−
2	3,4	45,-45	Middle	+	−
3	1,2	0,90	Middle	+	−

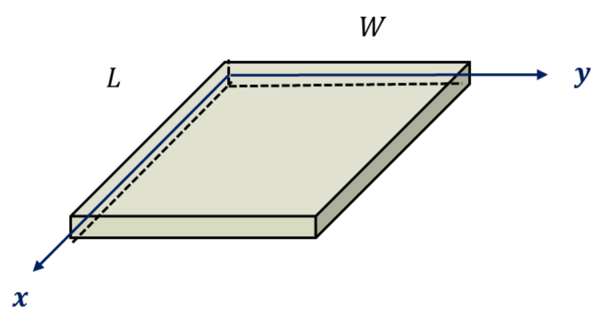
Inputs: Panels

❖ Panels:

Panels are easily created by using the predefined laminates, and by providing the length L and width W of the plate as shown below. Additional panels can be added by simply clicking the '+' sign on the extreme right (see below):

Panels

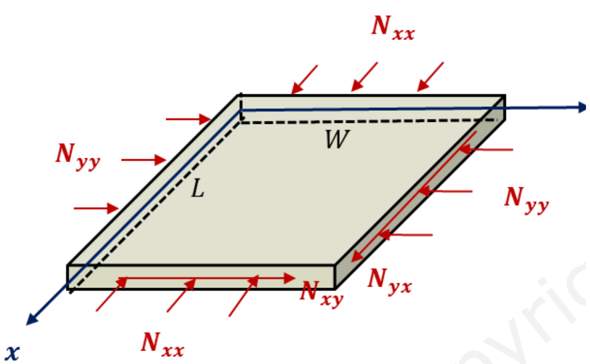
ID	Length	Width	Laminate		
1	15	10	1	+	−
2	15	10	2	+	−
3	15	10	3	+	−



Inputs: Loads

❖ **Loads:**

As mentioned earlier (see overview Section), various combinations of compressive/tensile and/or shear edge loads N_{xx}, N_{yy} and N_{xy} (force per unit length) can be applied to the panels (see figures below) to account for their effects on natural frequencies and modes of a simply-supported laminated composite plate.



Loads

ID	Panel	N_{xx}	N_{yy}	N_{xy}		
1	1	0	0	0	+	−
2	2	0	0	0	+	−
3	3	0	0	0	+	−
4	1	10	0	0	+	−
5	1	-10	0	0	+	−

Inputs: Analysis Options

❖ Analysis Options:

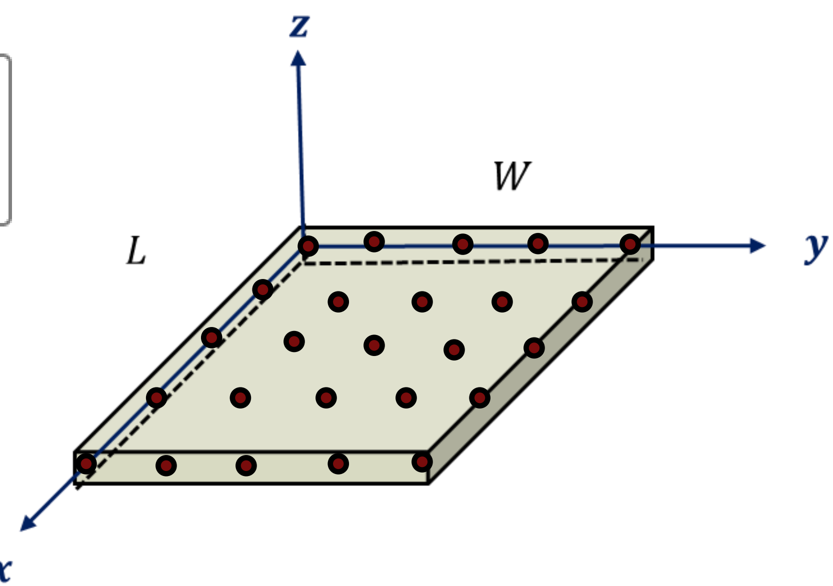
User has the option to define the number of terms in Fourier series solution of the solver. By default, $M = N = 8$ is assumed. $M = N$ can be varied from 2 to 21.

Output quantities from the analysis can be requested at select number of points (a.k.a grid points) in the plate domain. By default, a 5×5 grid is assumed within the domain of the plate bounded by $0 \leq x \leq L$ and $0 \leq y \leq W$ to output the analysis solution at 25 equally divided grid points (see below)

Default analysis options are also shown below:

Analysis Options

Number of Terms	Number of Points in x	Number of Points in y
8	5	5



Outputs

❖ Analysis Outputs:

Once all the Input steps viz., Materials, Plies / Laminae, Laminates, Panels, Loads and Analysis Options are completed, analyses can be run by clicking the "submit" button

Submit

Upon completion of analyses, an output is displayed for each Load ID in the window underneath

Output

```
3pc-solver004, v1.2b0

LOADS ID  PANEL ID
1         1

PANEL GEOMETRY
LENGTH: 15.00
WIDTH : 10.00

ANALYSIS OPTIONS
m = 8
n = 8

                                  MATERIAL PROPERTIES
ID            E1            E2            G12           G23           G13           v12           rho
aiaa-2009     1.80e+07      1.60e+06      8.70e+05      6.40e+05      8.70e+05      0.3000        0.00014900

     LAMINATE GEOMETRY
STACKING SEQUENCE (PLY ANG): [+45.0          , -45.0          , +45.0          , -45.0          , -45.0          , +45.0
STACKING SEQUENCE (PLY MAT): [aiaa-2009      , aiaa-2009      , aiaa-2009      , aiaa-2009      , aiaa-2009      , aiaa-2
```

Outputs

❖ Analysis Outputs:

Following information is output for each Load Case:

- Panel Geometry
- Terms in Fourier Series solution
- Number of Grid Points selected to get output information
- Material Properties and Laminate Information
- Laminate [A], [B], [D] stiffness matrices
- First Five (or lowest five) frequencies of vibration and mode shapes
- Grid Points coordinates x and y, and transverse displacements w for first five modes of vibration

Note that all output is consistent with the unit system used during the material, lamina, laminate, and loads Inputs.

- Laminate [A] stiffness matrices N/m or N/mm or lb/in
- Laminate [B] stiffness matrices N-m/m or N-mm/mm or lb-in/in
- Laminate [D] stiffness matrices N-m or N-mm or lb-in
- Applied Laminated Plate Force resultants in N/m, N/mm or lb/in
- Displacements in mm, m or in and Rotations in 1/mm, 1/m or 1/in
- Natural Frequencies , Hz

A typical output is shown below:

Output Text

3pc-solver004, v1.2b0

LOADS ID PANEL ID
1 1

PANEL GEOMETRY
LENGTH: 15.00
WIDTH : 10.00

ANALYSIS OPTIONS
m = 8
n = 8

OUTPUT OPTIONS
NUMBER OF POINTS IN X DIR: 5
NUMBER OF POINTS IN Y DIR: 5

MATERIAL PROPERTIES

ID	E1	E2	G12	G23	G13	v12
aiaa-2009	1.80e+07	1.60e+06	8.70e+05	6.40e+05	8.70e+05	0.3000

LAMINATE GEOMETRY
STACKING SEQUENCE (PLY ANG): [+45.0 , -45.0 , +45.0 , -45.0 , -45.0 , +45.0 , -45.0 , +45.0
]
STACKING SEQUENCE (PLY MAT): [aiaa-2009 , aiaa-2009 , aiaa-2009 , aiaa-2009 , aiaa-2009 , aiaa-2009 , aiaa-2009
, aiaa-2009]
TOTAL THICKNESS: 0.0420
TOTAL MASS: 0.0009
OFFSET: 0.0000

LAMINATE PROPERTIES
A MATRIX

+254160.97	+181080.97	+0.00
+181080.97	+254160.97	+0.00
+0.00	+0.00	+197298.39

A MATRIX - TRANSVERSE SHEAR

+31710.00	+0.00
+0.00	+31710.00

Output Text

B MATRIX

+0.00	+0.00	-0.00
+0.00	+0.00	-0.00
+0.00	+0.00	+0.00

D MATRIX

+37.36	+26.62	+9.57
+26.62	+37.36	+9.57
+9.57	+9.57	+29.00

LAMINATE INPLANE AND FLEXURAL ENGINEERING CONSTANTS

Ex	Ey	Gxy	vxy	vyx	Efx	Efy	Gfxy	vfxy	vfyx
+2.98e+06	+2.98e+06	+4.70e+06	+0.7125	+0.7125	+2.93e+06	+2.93e+06	+4.23e+06	+0.6859	+0.6859

APPLIED LOADS NATURAL FREQUENCY

NUMBER	NXX	NYY	NXY	HZ
1	0.0000	0.0000	0.0000	67.7402
2	0.0000	0.0000	0.0000	130.5990
3	0.0000	0.0000	0.0000	187.7086
4	0.0000	0.0000	0.0000	219.3856
5	0.0000	0.0000	0.0000	271.6349

Output Text

MODE SHAPES

X	Y	W1	W2	W3	W4	W5
0.0000	0.0000	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00
3.7500	0.0000	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00
7.5000	0.0000	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00
11.2500	0.0000	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00
15.0000	0.0000	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00
0.0000	2.5000	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00
3.7500	2.5000	+5.3330e-01	+6.2090e-01	+8.4180e-01	-2.0200e-01	-1.0415e+00
7.5000	2.5000	+7.0700e-01	-1.8960e-01	+9.8180e-01	+6.4120e-01	+3.6890e-01
11.2500	2.5000	+4.6330e-01	-7.6720e-01	+5.6920e-01	-7.7630e-01	+8.5670e-01
15.0000	2.5000	+0.0000e+00	-0.0000e+00	+0.0000e+00	-0.0000e+00	+0.0000e+00
0.0000	5.0000	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00
3.7500	5.0000	+7.0630e-01	+9.9800e-01	+1.0260e-01	-6.8410e-01	-2.6050e-01
7.5000	5.0000	+1.0043e+00	+0.0000e+00	+0.0000e+00	+9.8580e-01	+1.4040e-01
11.2500	5.0000	+7.0630e-01	-9.9800e-01	-1.0260e-01	-6.8410e-01	-2.6050e-01
15.0000	5.0000	+0.0000e+00	-0.0000e+00	-0.0000e+00	-0.0000e+00	-0.0000e+00
0.0000	7.5000	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00
3.7500	7.5000	+4.6330e-01	+7.6720e-01	-5.6920e-01	-7.7630e-01	+8.5670e-01
7.5000	7.5000	+7.0700e-01	+1.8960e-01	-9.8180e-01	+6.4120e-01	+3.6890e-01
11.2500	7.5000	+5.3330e-01	-6.2090e-01	-8.4180e-01	-2.0200e-01	-1.0415e+00
15.0000	7.5000	+0.0000e+00	-0.0000e+00	-0.0000e+00	-0.0000e+00	-0.0000e+00
0.0000	10.0000	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00
3.7500	10.0000	+0.0000e+00	+0.0000e+00	-0.0000e+00	-0.0000e+00	+0.0000e+00
7.5000	10.0000	+0.0000e+00	+0.0000e+00	-0.0000e+00	+0.0000e+00	+0.0000e+00
11.2500	10.0000	+0.0000e+00	-0.0000e+00	-0.0000e+00	-0.0000e+00	-0.0000e+00
15.0000	10.0000	+0.0000e+00	-0.0000e+00	-0.0000e+00	-0.0000e+00	-0.0000e+00

Inputs and Outputs: Consistent Units

Quantity	SI System 1	SI system 2	US System
$E_1, E_2, G_{12}, G_{13}, G_{23}$ $E_x, E_y, G_{xy}, E_{fx}, E_{fy}, G_{fxy}$	$MPa\ (N/mm^2)$	$Pa\ (N/m^2)$	$Psi\ (lb/in^2)$
α_1 , α_2 , α_x , α_y, α_{xy}	$mm/mm/$℃	$m/m/$℃	$in/in/$℉
β_1, β_2 , β_x , β_y, β_{xy}	$mm/mm/Kg/Kg$	$m/m/Kg/Kg$	$in/in/lb/lb$
$\sigma_{11}^T, \sigma_{11}^C, \sigma_{22}^T, \sigma_{22}^C\ \tau_{12}^S, \sigma_1, \sigma_2, \tau_{12}, \tau_{23}, \tau_{13},$ $\sigma_x, \sigma_y, \tau_{xy}, \tau_{yz}, \tau_{xz}$	$MPa\ (N/mm^2)$	$Pa\ (N/m^2)$	$Psi\ (lb/in^2)$
$\varepsilon_{11}^T, \varepsilon_{11}^C, \varepsilon_{22}^T, \varepsilon_{22}^C, \gamma_{12}, \varepsilon_1, \varepsilon_2, \gamma_{12}, \gamma_{13}, \gamma_{23}, \varepsilon_{x0},$ $\varepsilon_{y0}, \gamma_{xy0}, \gamma_{yz0}, \gamma_{xz0}\ \varepsilon_x, \varepsilon_y, \gamma_{xy}, \gamma_{yz}, \gamma_{xz}$	mm/mm	m/m	in/in
$\kappa_{x0}, \kappa_{y0}, \kappa_{xy0}$	$1/mm$	$1/m$	$1/in$
$N_{xx}, N_{yy}, N_{xy}, N_{xx}^T, N_{yy}^T, N_{xy}^T,$ $N_{xx}^H, N_{yy}^H, N_{xy}^H$, [A]	N/mm	N/m	lb/in
[B]	$N - mm/mm$	$N - m/m$	$lb - in/in$
[D]	$N - mm$	$N - m$	$lb - in$
ΔT	℃	℃	℉
ΔC	Kg/Kg	Kg/Kg	lb/lb
Ply Angle, θ	Degree	Degree	Degree
Ply or Laminate thickness or Offset or w	mm	m	in
Frequency	Hz	Hz	Hz

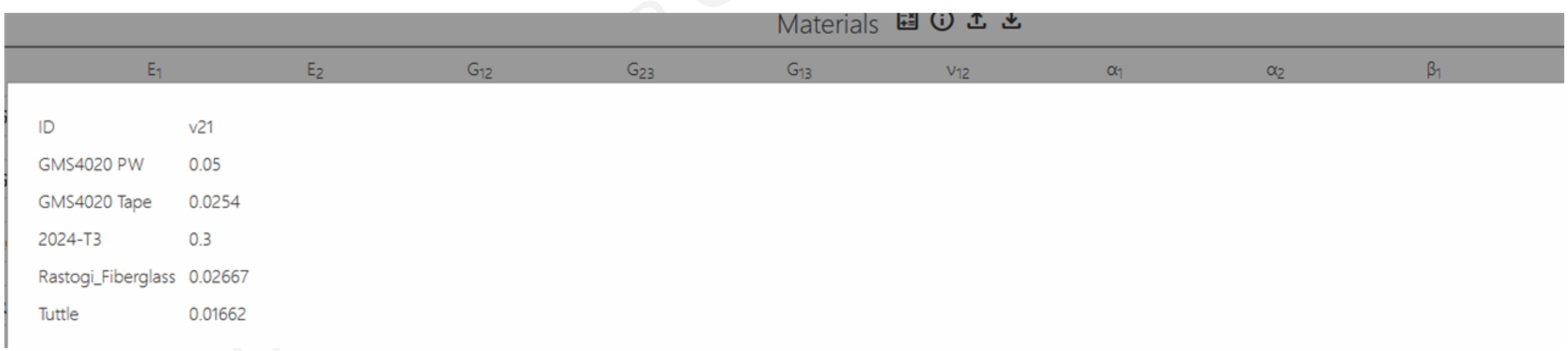
Other Features

❖ Upload/Download:

Users can upload and download Material properties, Plies, Laminates, Panels and Loads data files (*.json) using the upload ⭱ and download ⭳ buttons next to these inputs.

❖ Additional Output:

Users can review a few intermediate calculations such as minor Poison's ratios ν_{21}, Q_{ij} for each ply type and laminate ABD by using the calculation button . Few such examples are shown below:



3P COMPOSITES

Other Features

Plies

ID	Angle (deg)	Material	Thickness
1	0	Tuttle	0.0075
2	90	Tuttle	0.0075

ID	Q	Q44	Q55	Qbar	Q44bar	Q45bar	Q55bar
1	[[22627882.74, 376125.7, 0.0], [376125.7, 1106252.04, 0.0], [0.0, 0.0, 640000.0]]	640000	640000	[[22627882.74, 376125.7, 0.0], [376125.7, 1106252.04, 0.0], [0.0, 0.0, 640000.0]]	640000	0	640000
2	[[22627882.74, 376125.7, 0.0], [376125.7, 1106252.04, 0.0], [0.0, 0.0, 640000.0]]	640000	640000	[[1106252.04, 376125.7, 0.0], [376125.7, 22627882.74, 0.0], [0.0, 0.0, 640000.0]]	640000	0	640000
3	[[22627882.74, 376125.7, 0.0], [376125.7, 1106252.04, 0.0], [0.0, 0.0, 640000.0]]	640000	640000	[[6761596.54, 5481596.54, 5380407.67], [5481596.54, 6761596.54, 5380407.67], [5380407.67, 5380407.67, 5745470.85]]	640000	0	640000
4	[[22627882.74, 376125.7, 0.0], [376125.7, 1106252.04, 0.0], [0.0, 0.0, 640000.0]]	640000	640000	[[6761596.54, 5481596.54, -5380407.67], [5481596.54, 6761596.54, -5380407.67], [-5380407.67, -5380407.67, 5745470.85]]	640000	0	640000

Laminates

ID	Stacking Sequence	Stacking Sequence (Angle)	Offset
1	1,1,1,1,1,1,1,1	0,0,0,0,0,0,0,0	Middle
2	1,2,1,2,2,1,2,1	0,90,0,90,90,0,90,0	Middle
3	3,4,3,4,4,3,4,3	45,-45,45,-45,-45,45	Middle

ID	Thickness	A	B	D	A44	A45	A55
1	0.06	[[1357672.96, 22567.54, 0.0], [22567.54, 66375.12, 0.0], [0.0, 0.0, 38400.0]]	[[0.0, 0.0, 0.0], [0.0, -0.0, 0.0], [0.0, 0.0, 0.0]]	[[407.3, 6.77, 0.0], [6.77, 19.91, 0.0], [0.0, 0.0, 11.52]]	38400	0	38400
2	0.06	[[712024.04, 22567.54, 0.0], [22567.54, 712024.04, 0.0], [0.0, 0.0, 38400.0]]	[[0.0, 0.0, 0.0], [0.0, -0.0, 0.0], [0.0, 0.0, 0.0]]	[[286.24, 6.77, 0.0], [6.77, 140.97, 0.0], [0.0, 0.0, 11.52]]	38400	0	38400
3	0.06	[[405695.79, 328895.79, 0.0], [328895.79, 405695.79, 0.0], [0.0, 0.0, 344728.25]]	[[0.0, -0.0, 0.0], [-0.0, -0.0, 0.0], [0.0, 0.0, -0.0]]	[[121.71, 98.67, 36.32], [98.67, 121.71, 36.32], [36.32, 36.32, 103.42]]	38400	0	38400

3P COMPOSITES
PRODUCIBILITY PERFORMANCE PROFITABILITY

General Information

- Subscription fee to access 3pcsolver004 is $39/year per for a single-login license

- Training module 3pcmodule004 supports the solver 3pcsolver004. Users' can buy the training module 3pcmodule001 online at

  https://www.3pcomposites.com/

- 3P Composites, LLC can conduct online or in-class trainings for the 3pcsolver004 and 3pcmodule004. The training can be adapted to meet the requirements of individual needs and/or industrial applications

- For questions, issues, comments, suggestions, trainings, please contact us at 3pcomps@gmail.com. Your feedback is appreciated in helping us continuously improve the product

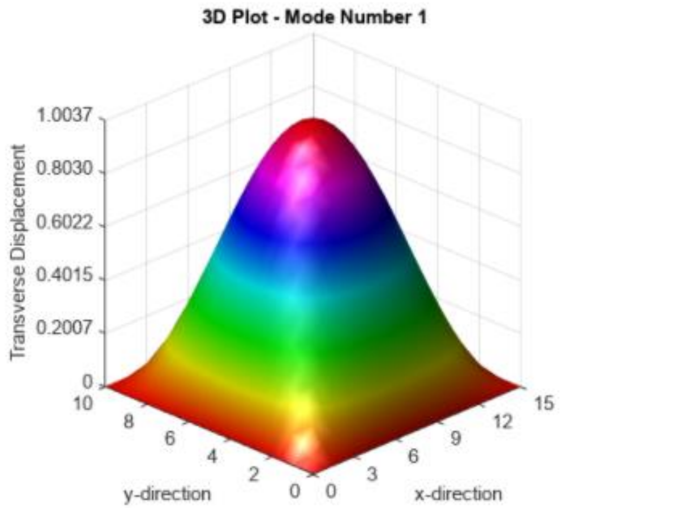
Example: Natural Frequencies $[\pm 45]_{2s}$

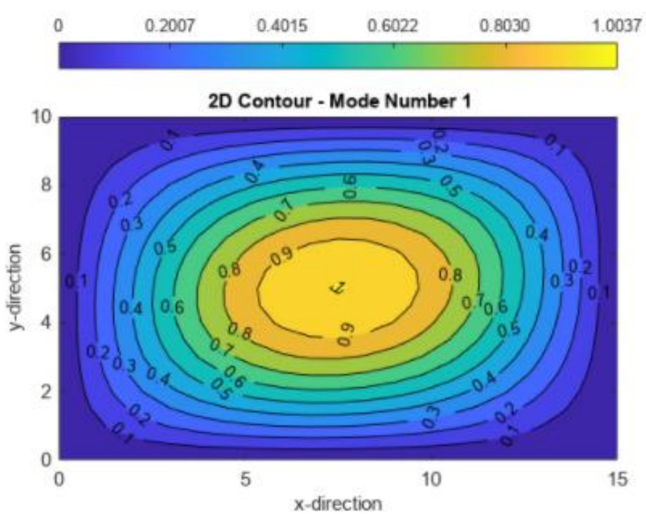
- Lamina Properties: $E_1 = 1.8e7\, psi, E_2 = 1.6e6\, psi$; $G_{12} = G_{13} = 8.7e5\, psi$, $G_{23} = 6.4e5\, psi; \nu_{21} = 0.3, t_{ply} = 0.00525\, inch$, $\rho = 1.49 \times 10^{-4} \text{lb} - \text{sec}^2/\text{in}^4$
- Plate Dimensions: L = 15 in., W = 10 in., Aspect Ratio $\frac{L}{W} = 1.5$
- $D_{16} \neq D_{26} \neq 0$ (shows as skewed modes)
- Five load cases:
  - I: No applied edge loads
  - II: Applied Axial Edge Tension N_{xx} = 10 lb/in
  - III: Applied Axial Edge Compression N_{xx} = -10 lb/in
  - IV: Applied Edge Shear N_{xy} = 10 lb/in
  - V: Applied Edge Shear N_{xy} = -10 lb/in
- MATLAB scripts are used to create both 3D and 2D contour plots of the transverse displacement w depicting the natural free vibration mode shapes of simply-supported laminated composite plates

	CASE				
Modes, Hz	I	II	III	IV	V
1	67.74	79.833	52.94	63.061	68.54
2	130.60	155.02	100.03	118.08	133.58
3	187.71	192.87	180.57	188.79	188.71
4	219.39	251.31	182.56	202.4	226.59
5	271.64	286.10	257.24	271.0	273.50

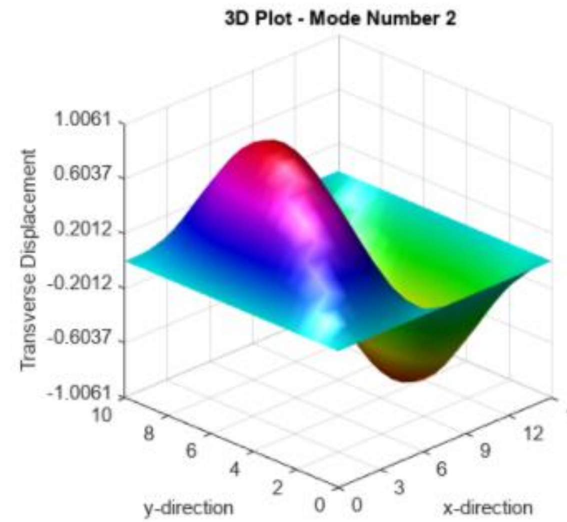
Case I: Natural Frequencies & Mode Shapes $[\pm 45]_{2s}$

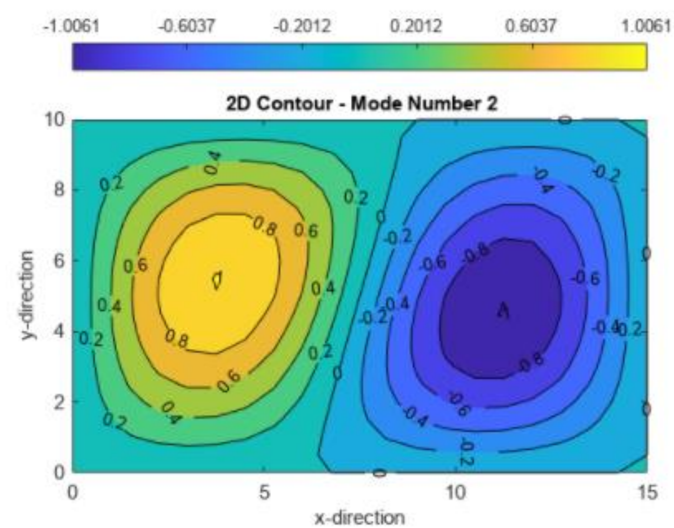
First Mode: 67.74 Hz





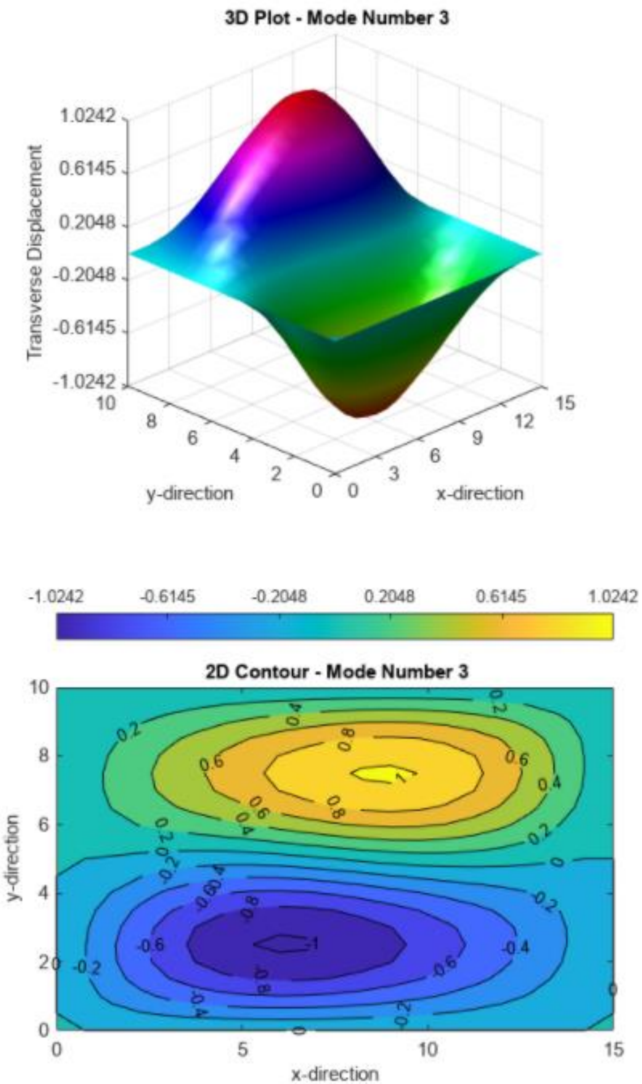
Second Mode: 130.6 Hz



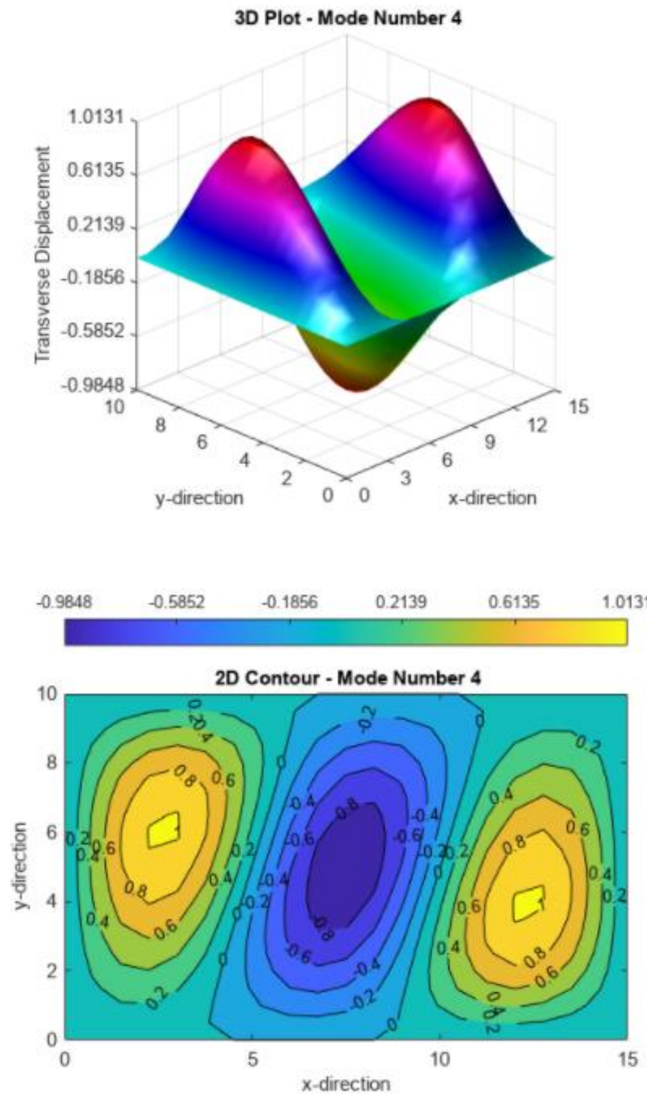


Case I: Natural Frequencies & Mode Shapes $[\pm 45]_{2s}$

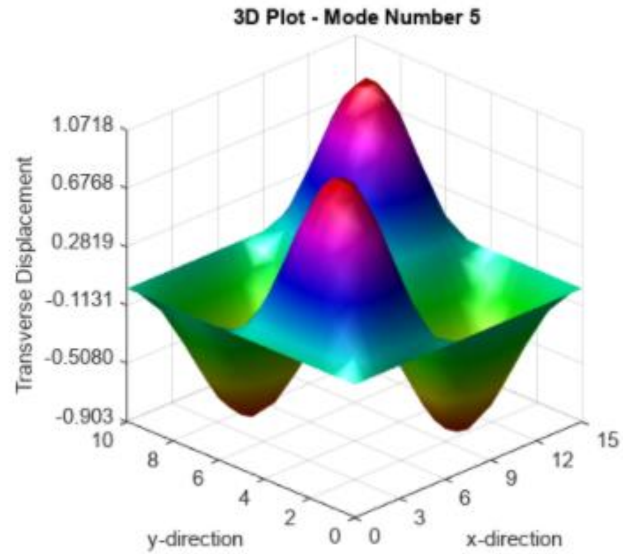
Third Mode: 187.71 Hz



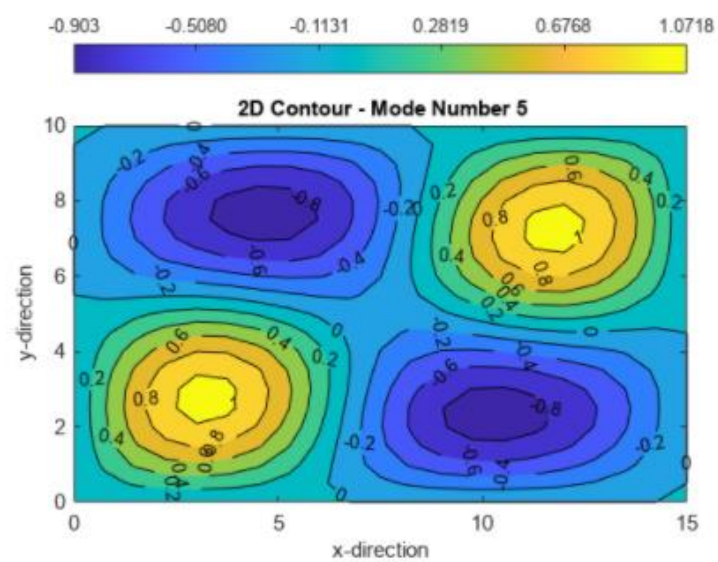
Fourth Mode: 219.39 Hz



Case I: Natural Frequencies & Mode Shapes $[\pm 45]_{2s}$

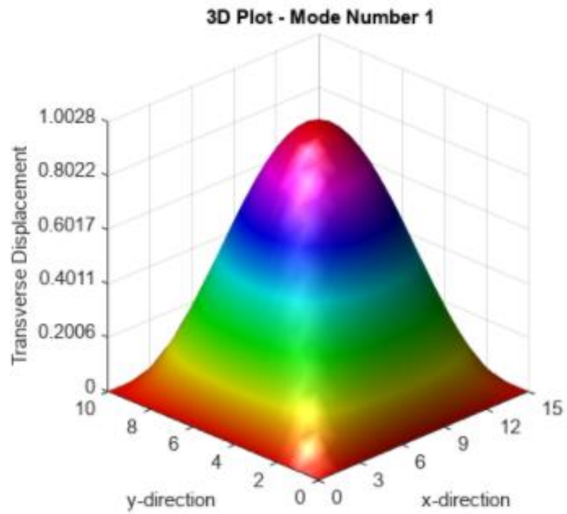


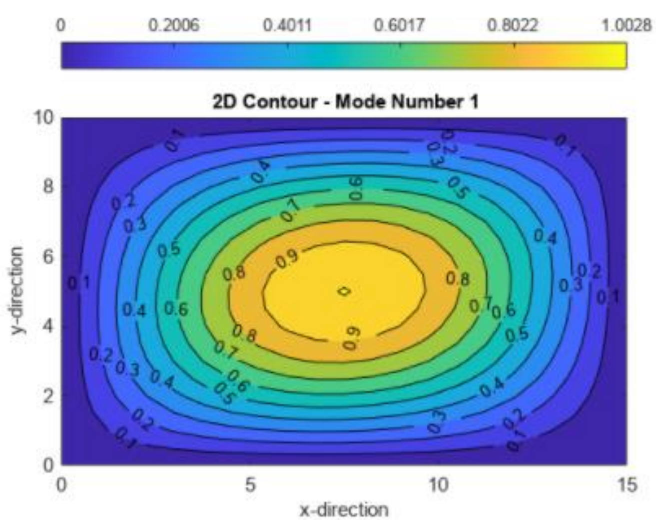
Fifth Mode: 271.64 Hz



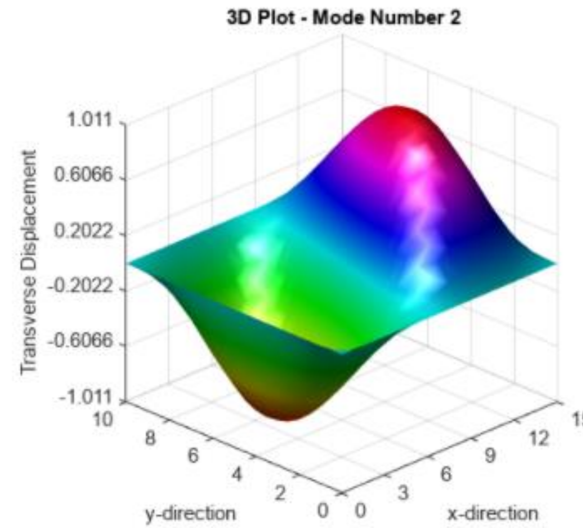
Case II: Natural Frequencies & Mode Shapes $[\pm 45]_{2s}$

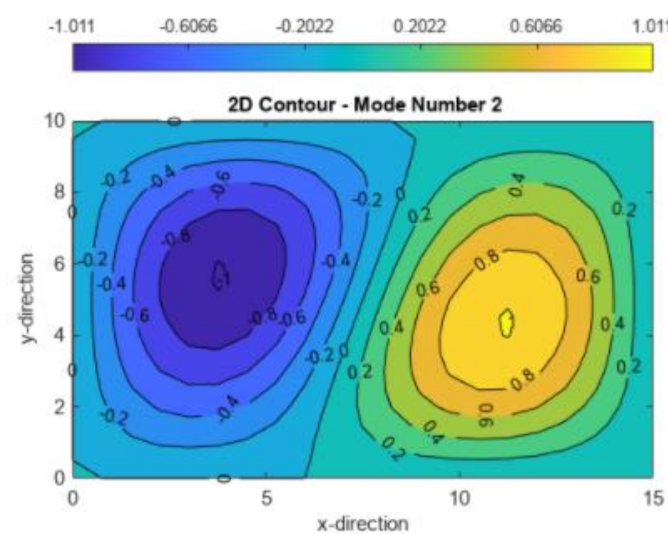
First Mode: 79.83 Hz





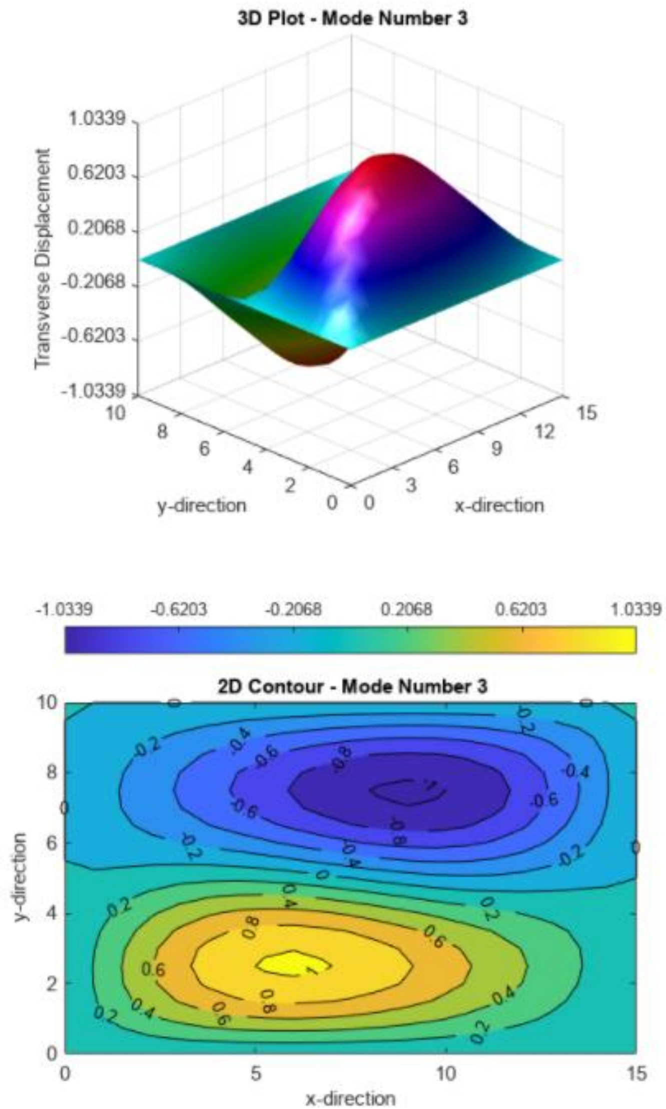
Second Mode: 155.02 Hz



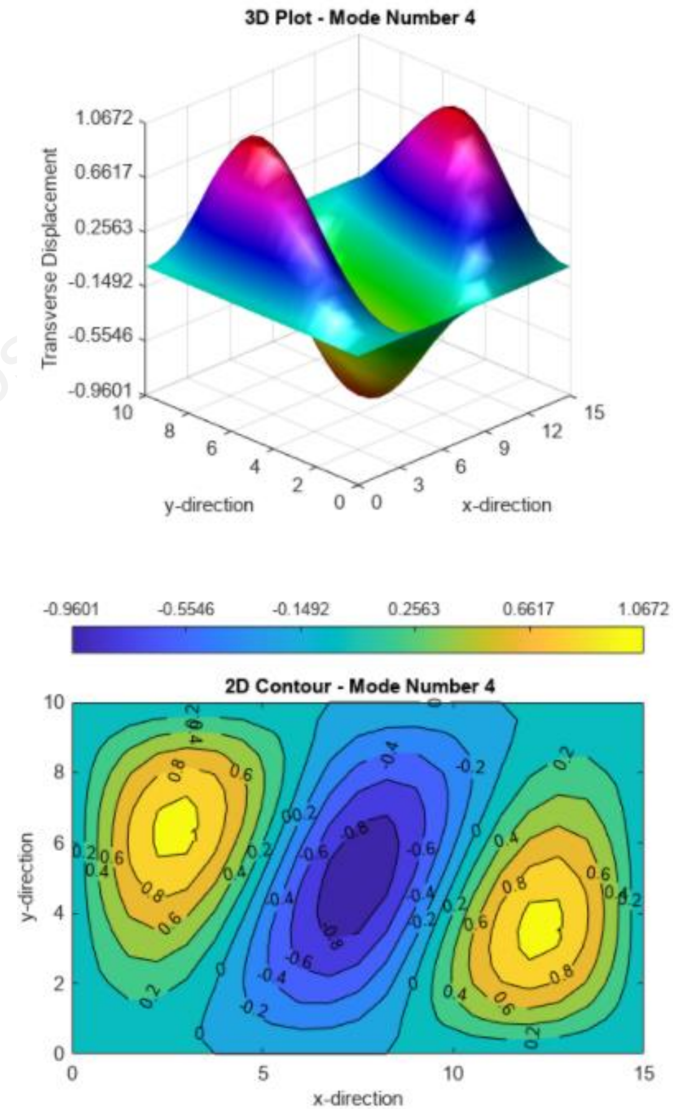


Case II: Natural Frequencies & Mode Shapes $[\pm 45]_{2s}$

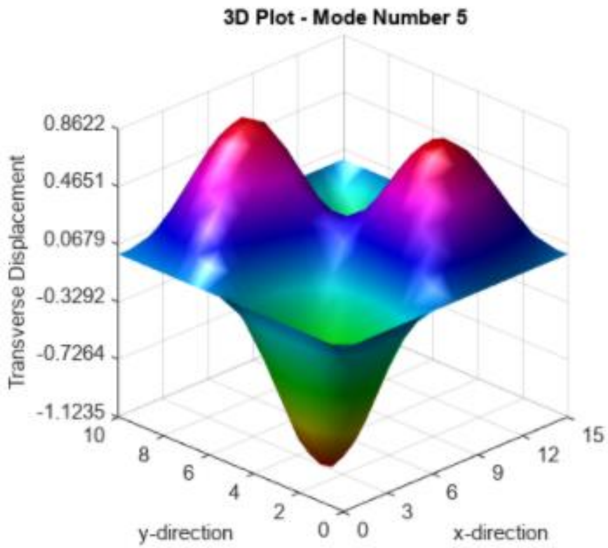
Third Mode: 192.87 Hz



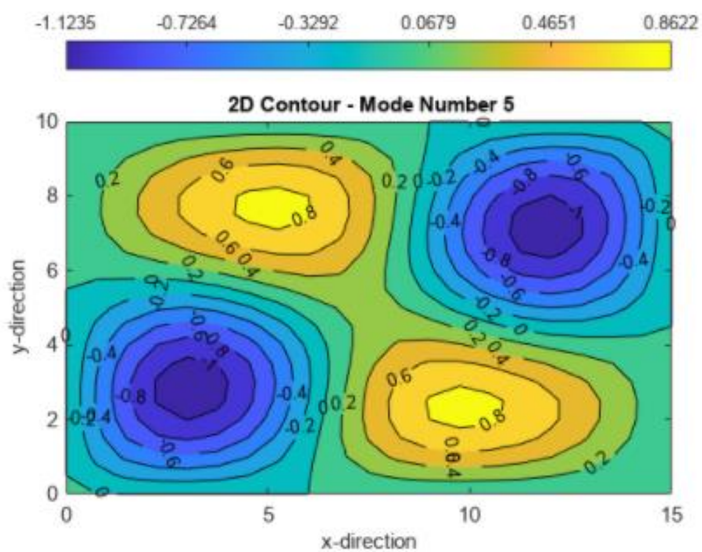
Fourth Mode: 251.31 Hz



Case II: Natural Frequencies & Mode Shapes $[\pm 45]_{2s}$



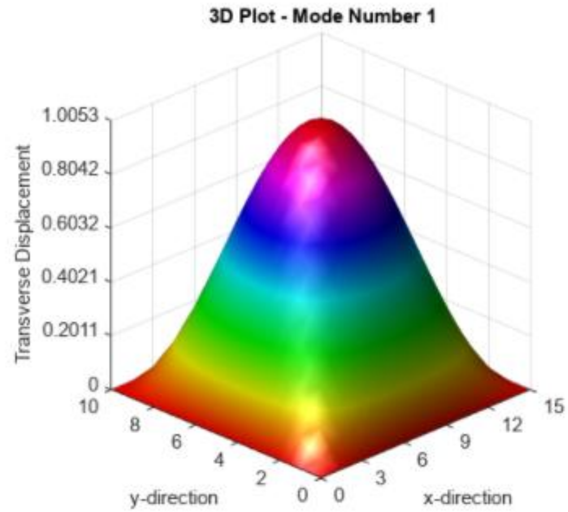
Fifth Mode: 286.1 Hz



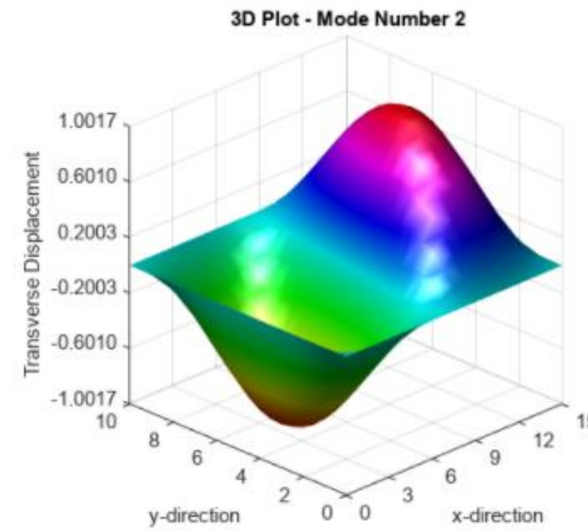
3P COMPOSITES
PRODUCIBILITY
PERFORMANCE
PROFITABILITY

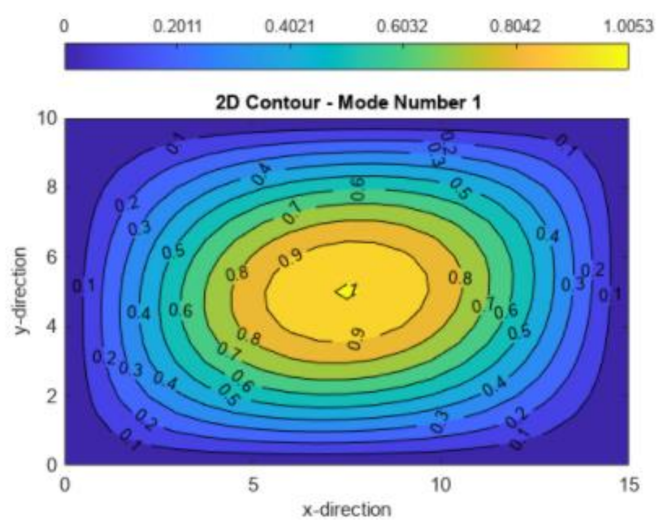
Case III: Natural Frequencies & Mode Shapes $[\pm 45]_{2s}$

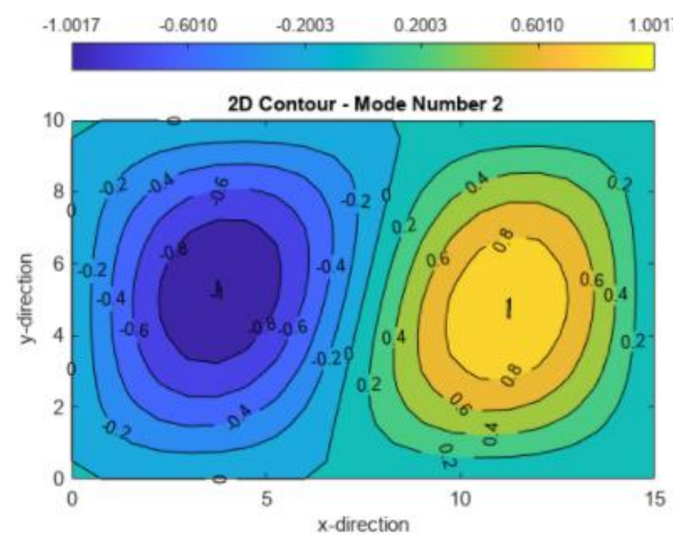
First Mode: 52.94 Hz



Second Mode: 100.03 Hz

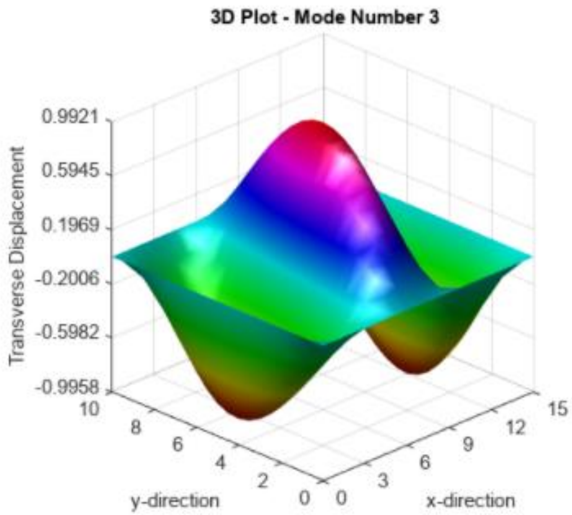


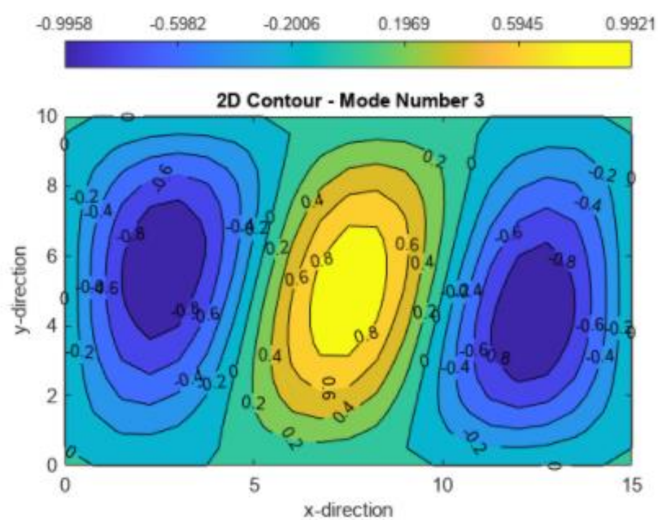




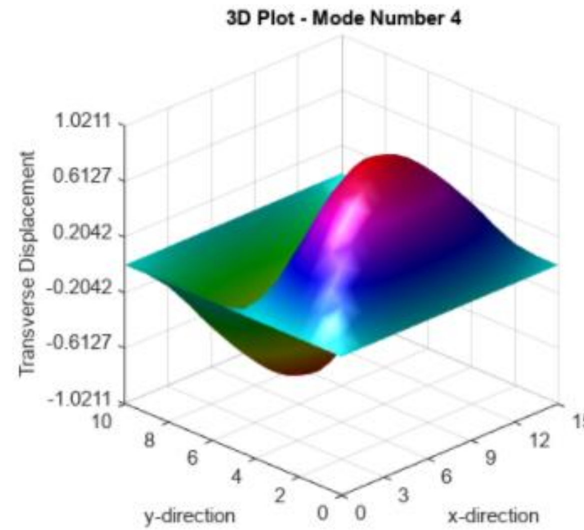
Case III: Natural Frequencies & Mode Shapes $[\pm 45]_{2s}$

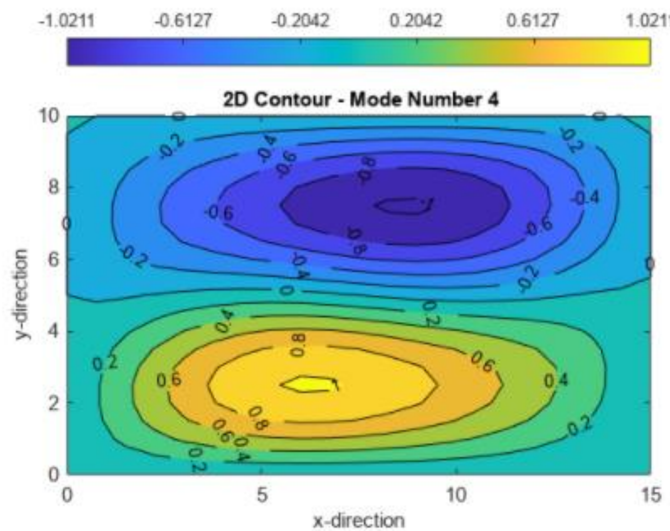
Third Mode: 180.67 Hz





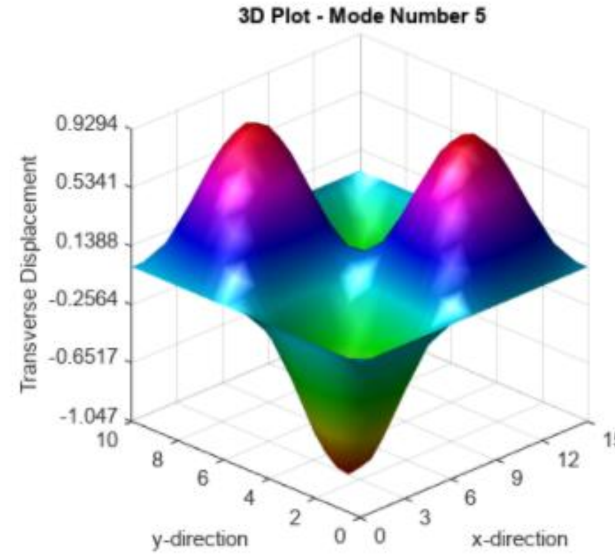
Fourth Mode: 182.56 Hz

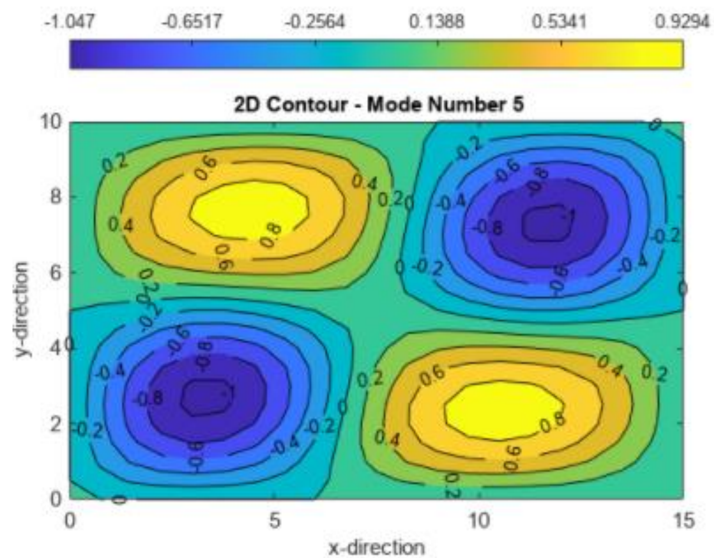




Case III: Natural Frequencies & Mode Shapes $[\pm 45]_{2s}$

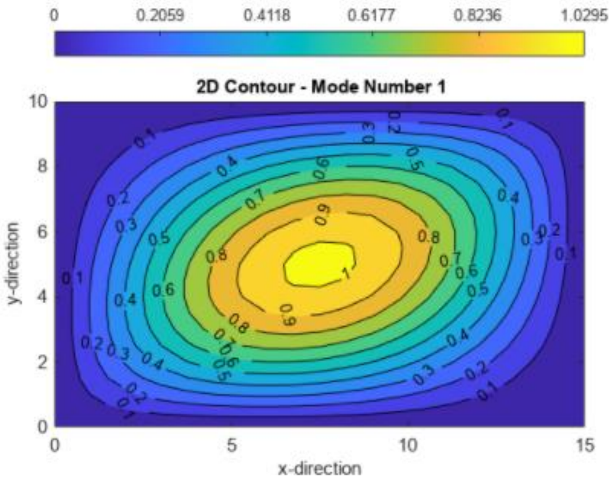
Fifth Mode: 257.24 Hz

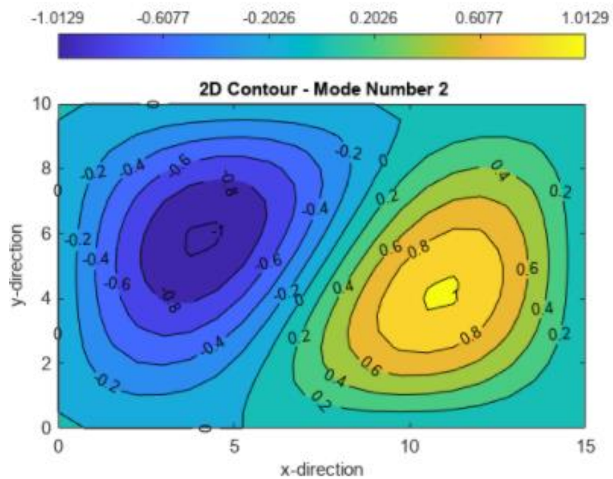


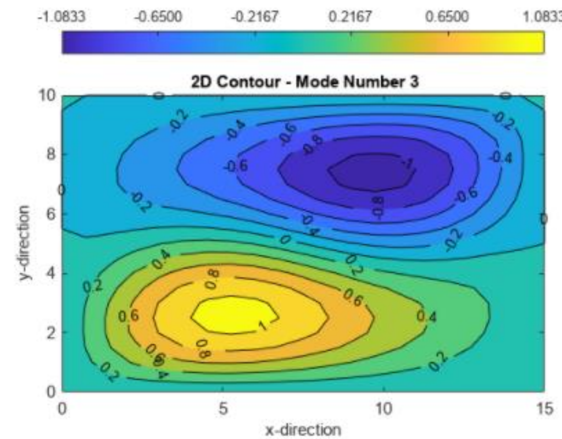


3P COMPOSITES

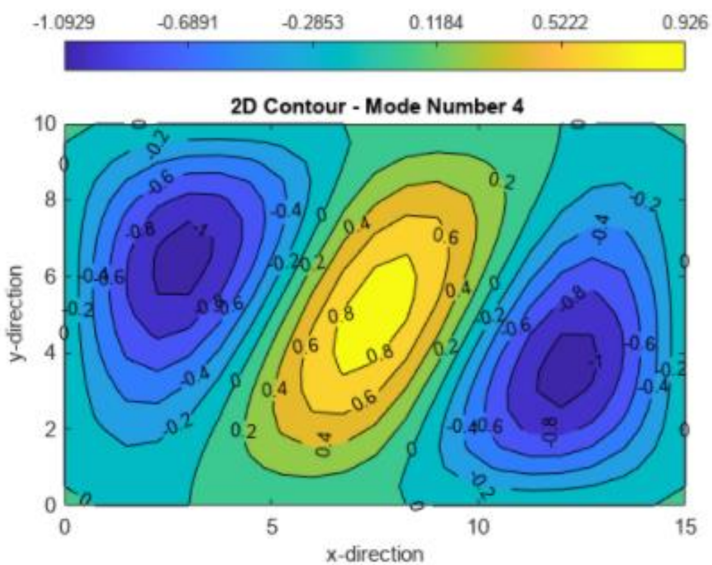
Case IV: Natural Frequencies & Mode Shapes $[\pm 45]_{2s}$

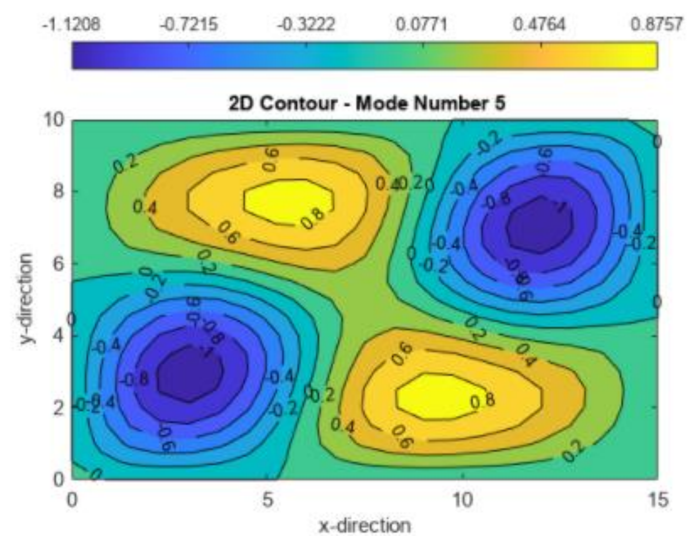






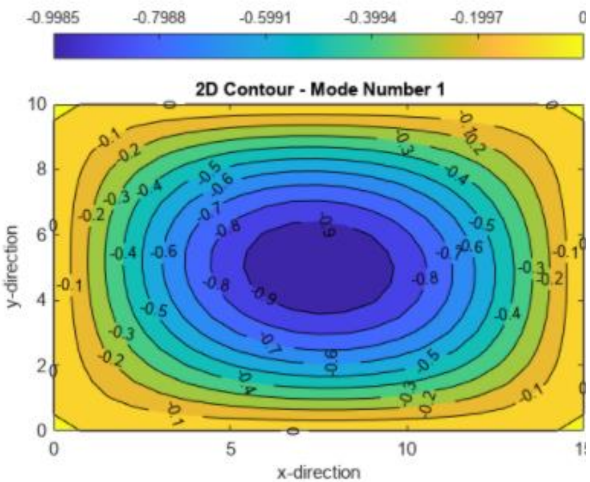
Frequencies Hz
63.061
118.08
188.79
202.4
271.0

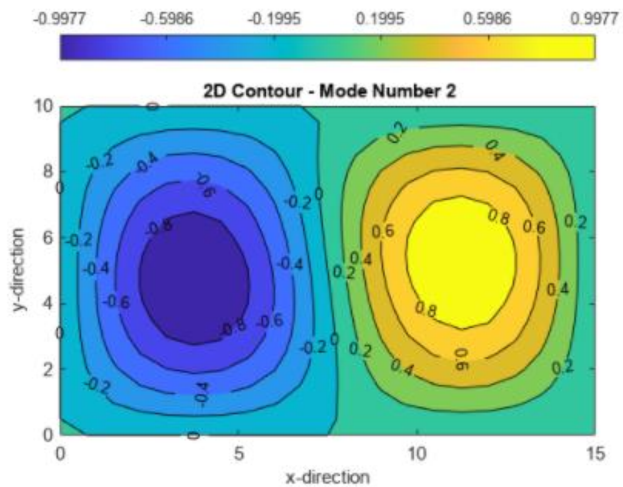


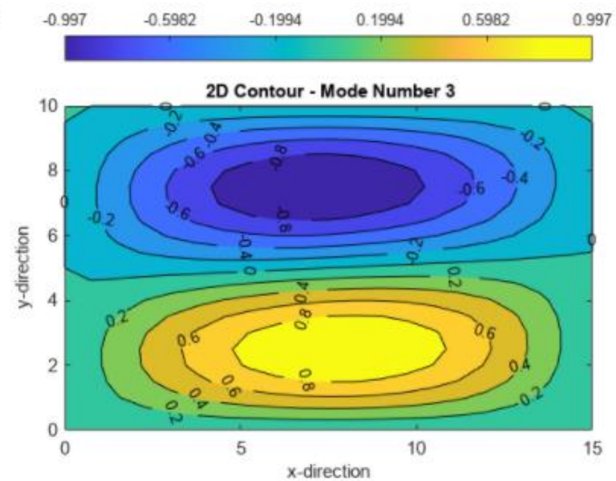


3P COMPOSITES

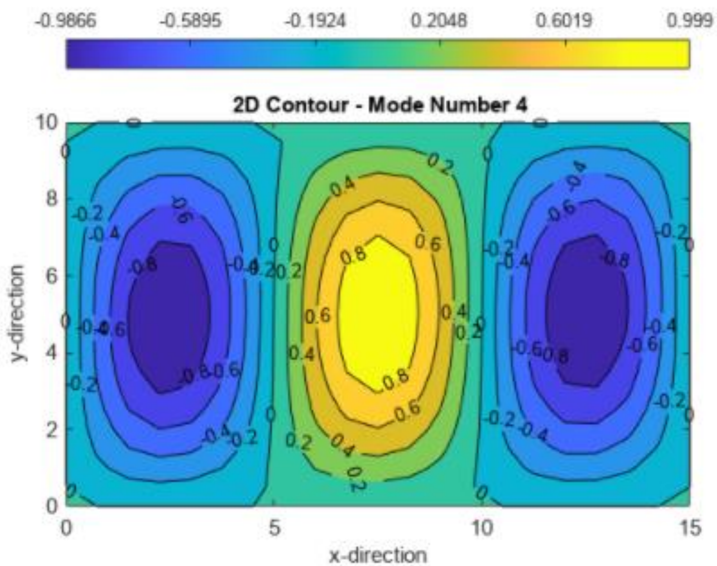
Case V: Natural Frequencies & Mode Shapes $[\pm 45]_{2s}$

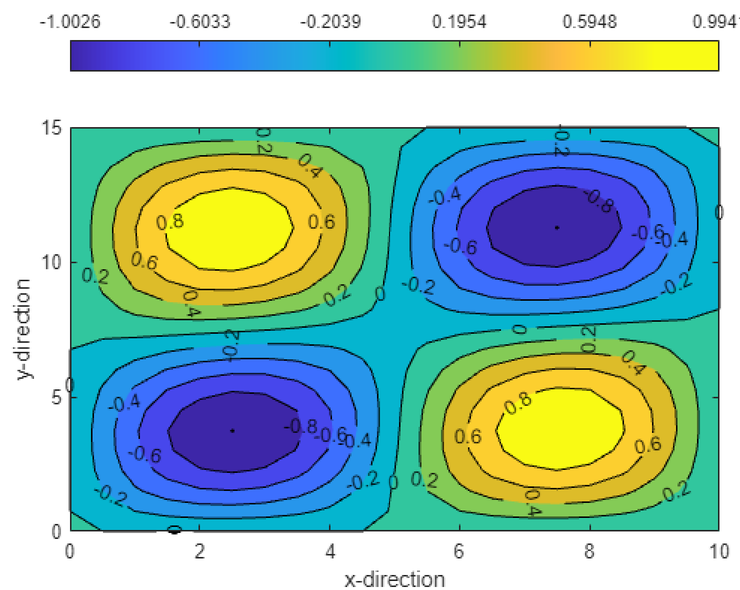




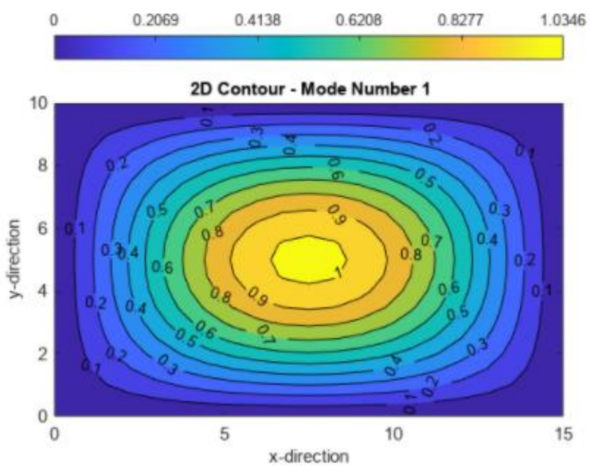


Frequencies Hz
68.54
133.58
188.71
226.59
273.50

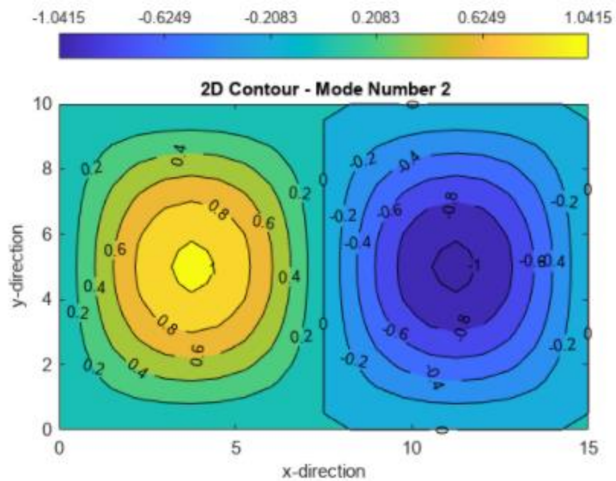




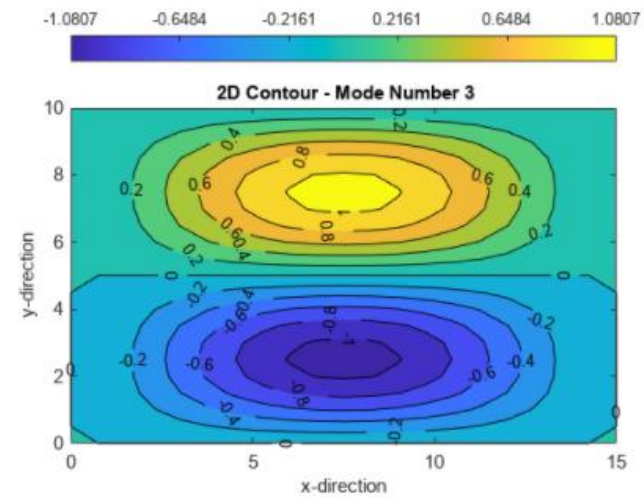
Natural Frequencies & Mode Shapes $[\pm 45]_T$



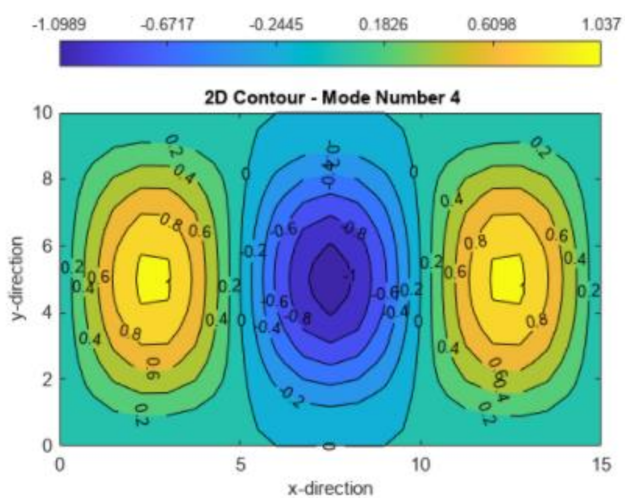
First Mode: 15.24 Hz



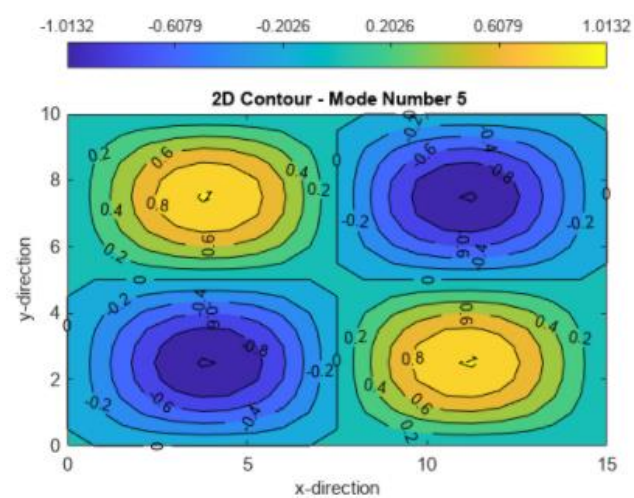
Second Mode: 28.91 Hz



Third Mode: 37.52 Hz

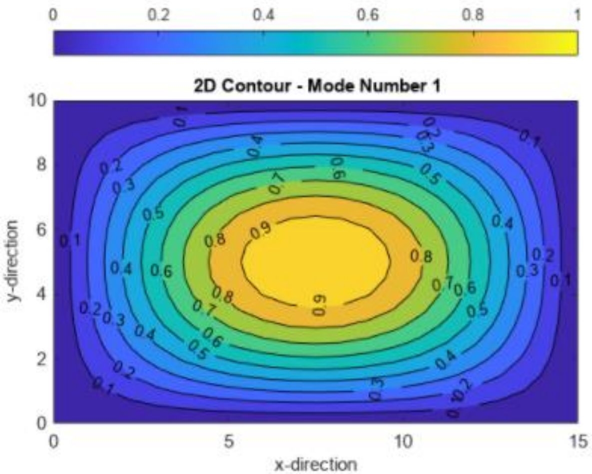


Fourth Mode: 47.32 Hz

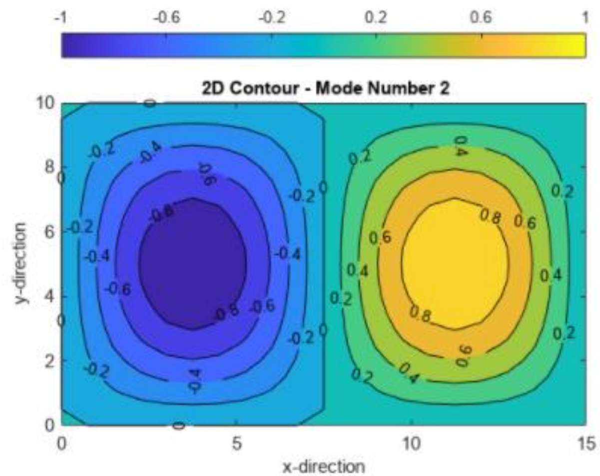


Fifth Mode: 51.67 Hz

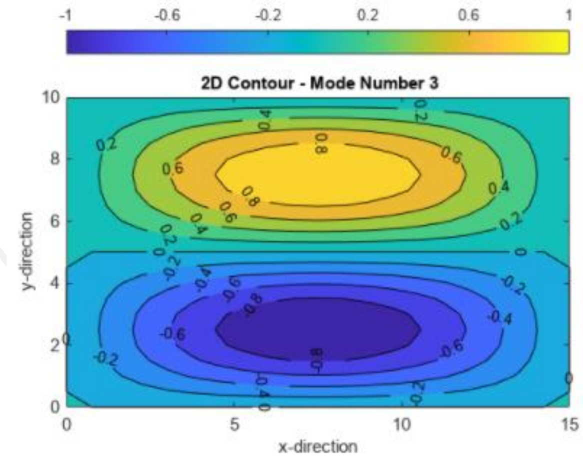
Natural Frequencies & Mode Shapes $[0/90]_T$



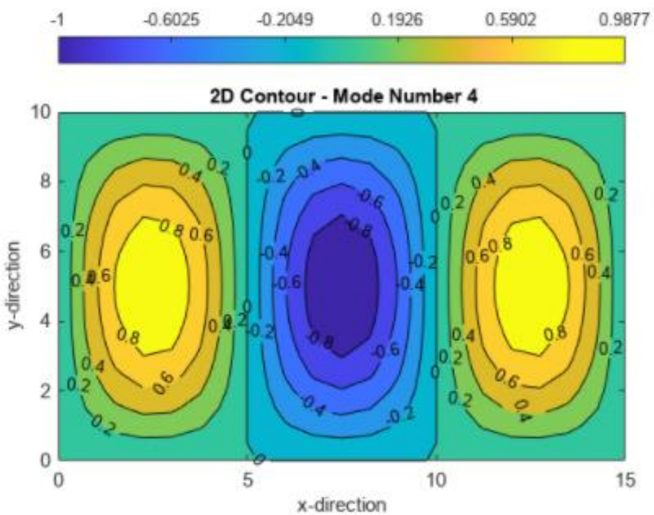
First Mode: 10.58 Hz



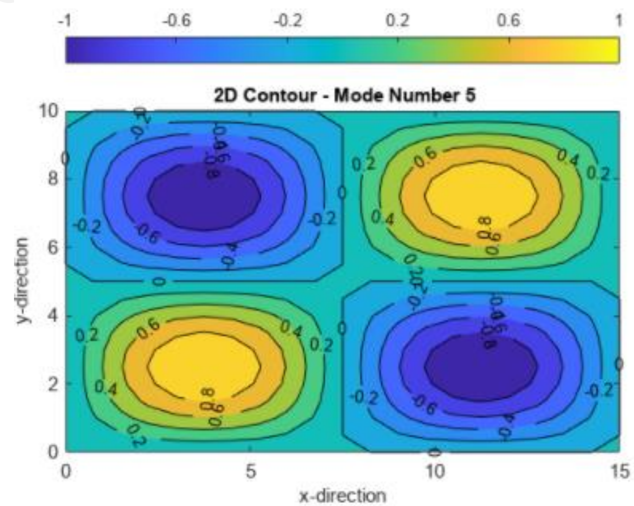
Second Mode: 20.07 Hz



Third Mode: 35.51 Hz



Fourth Mode: 38.09 Hz



Fifth Mode: 42.31 Hz