3PC SOLVER 008

Free Vibration Analysis of Simply Supported Sandwich Composite Plates

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1/30/2023

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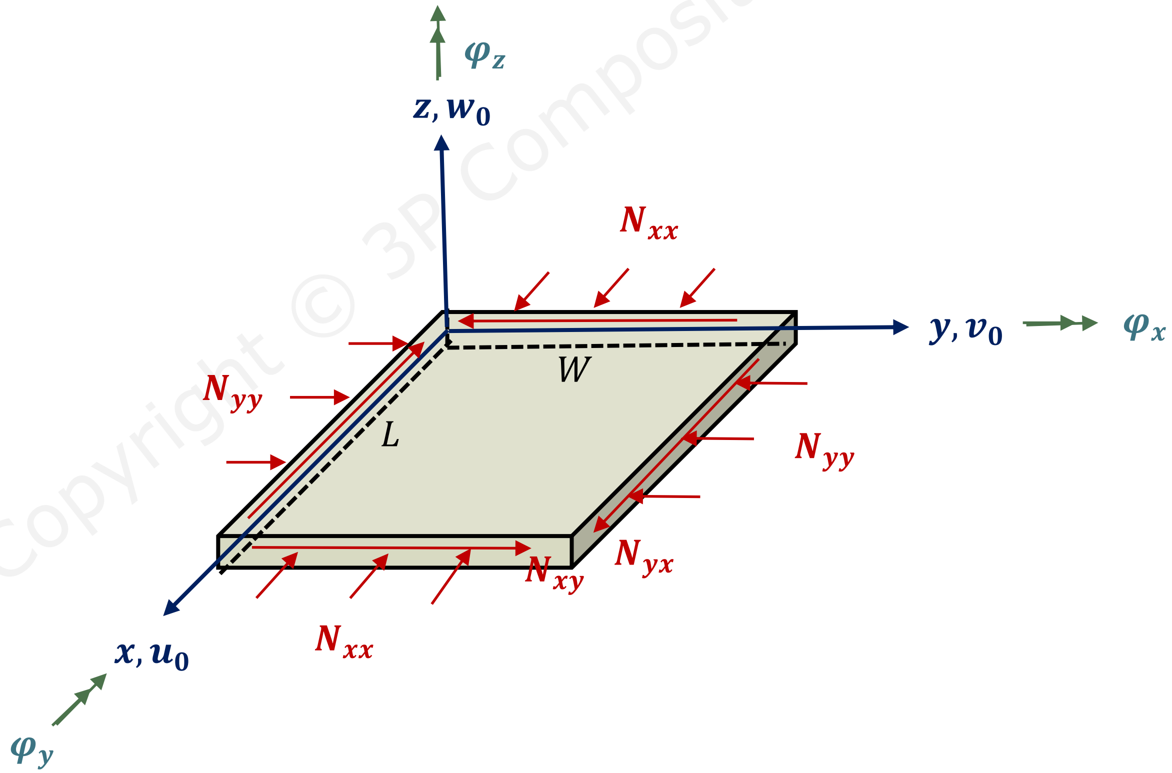
Contents: 3pcsolver008

Overview

❖ 3pcsolver008 performs free vibration analysis of simply-supported sandwich plates. 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 sandwich plates with composite/laminated face sheets are computed by this solver. Furthermore, 3pcsolver008 solver can include the effects of in-plane mechanical tension/compression and/or shear edge loads on the natural frequencies of vibration and mode shapes of simply-supported sandwich plates



Applications

- The analysis is applicable to the sandwich panels manufactured from face sheets that are either fiber-reinforced laminates or metallic sheets and a core that is either isotropic or orthotropic. The face sheets can consist of single-material laminate(s) or hybrid (multi-material) laminates, one or multiple broad forms of lamina type or fiber types or single or multiple materials systems or their combinations
- Core of the sandwich structure can be isotropic or orthotropic, and
  - Metallic such as Aluminum, Titanium, etc.
  - Non-metallic such as Nomex, Balsa wood, Rohacell, Foam core, Glass Fiber, Kevlar, etc.
- Face sheets of the sandwich structure can have 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 unidirectional, bi-directional 2D textile weaves like plain weave, twill and harness, biaxial and triaxial braids, chopped random continuous 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.

Theoretical Background

- **3pcsolver008** 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 sandwich 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 simply-supported sandwich plates 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 system of equations given above, K_{ij} are the stiffness terms containing the sandwich plates' A_{ij}, B_{ij} and D_{ij}. 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 sandwich plate. ω_{mn} is the circular or angular frequency (radian/second) of vibration. Effects of applied edge loads from mechanical loadings are contained in the K_{33} stiffness term

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 sandwich plates including the effects 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 sandwich plate

❖ Given the lamina/ply and core material properties, laminate stack-up and its length and width dimensions, 3pcsolver008 solver calculates natural frequencies of vibration and associated mode shapes for a sandwich plate

Theoretical Background

- The 3pcsolver008 is a unique solver which is based on FSDT of laminated plates, employs a closed-form Ritz solution procedure, considers the fully anisotropic effects of face sheet laminates, and obtain natural frequencies and mode shapes of sandwich plates with various types of factsheets and cores. In case of laminated composite factsheets, all types of face sheet 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 vibration analysis of sandwich plates. Most closed-form analyses neglect these coupling effects due to the complexity in deriving the system of equations, and hence, assume the laminated face sheets as being specially orthotropic (i.e. $A_{i6} = B_{ij} = D_{i6} = 0, i = 1,2 , j = 1,2,6$)

- Solution to the above system of equations 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. Numerous examples are solved using **3pcsolver008** solver, and results are compared with those (i) obtained from standard commercially available finite element analysis software, and (ii) available in open literature

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Theoretical Background

- Many different types of ply and core material systems, ply orientations, face sheet laminate stack ups, sandwich plate dimensions, and types of transverse loading are considered to check the accuracy of the solver. Excellent correlations are obtained in all cases

- Details of the theoretical approach along with numerous verification and application examples are available in the training module **3pcmodule008**

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 of user's input:

  - Materials
  - Plies / Laminae
  - Cores
  - Laminates
  - Sandwich 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	+	–

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Inputs: Plies

❖ Plies/Laminae:

Types of plies in a face sheet 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	Uni	0.005	+	−
2	45	PW	0.010	+	−
3	90	Uni	0.005	+	−

Plies

ID	Angle (deg)	Material	Thickness		
1	0	CEP	0.005	+	−
2	30	Flax	0.010	+	−
3	60	CEP	0.005	+	−

Plies

ID	Angle (deg)	Material	Thickness		
1	0	CEP	0.005	+	−
2	45	CEP	0.005	+	−
3	-45	CEP	0.005	+	−
4	90	CEP	0.005	+	−
5	0	Flax	0.01	+	−

Inputs: Cores

❖ Cores:

Types of cores are required as input. Each core type is defined by its orientation angle in degrees, material type (isotropic or orthotropic) and its thickness. Multiple core types can be input by simply clicking the '+' sign on the extreme right. A few examples of the core type inputs are shown below:

Cores

ID	Angle (deg)	Material	Thickness		
1	0	Ncore	0.5	+	−
2	90.0	Ncore	0.5	+	−
3	0	Ncore	1.0	+	−

Inputs: Laminates

❖ **Laminates:**

Multiple face sheet laminates can be quickly created by defining their stacking sequences using the plies defined in the previous step. Face sheet 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		
CEP-QI	2,3,1,4,4,1,3,2	45,-45,0,90,90,0,-45	Middle	+	–
CEP-Cross Ply	1,4,1,4,1,4,1,4	0,90,0,90,0,90,0,90	Bottom	+	–
CEP-Angle Ply	2,3,2,3,2,3,2,3	45,-45,45,-45,45,-45	Top	+	–
CEP-Flax Hybrid	1,2,3,4,5	0,45,-45,90,0	Middle	+	–

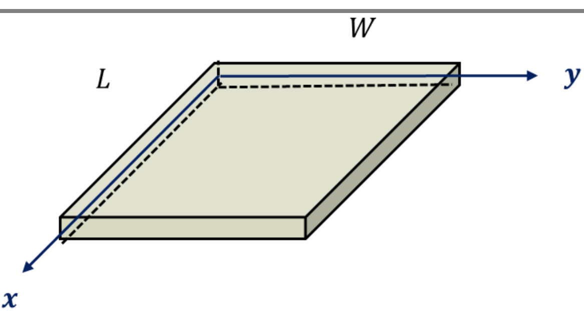
Inputs: Sandwich Panels

❖ Sandwich Panels:

Sandwich Panels are defined by its Length and width dimensions and the definitions of face sheet laminates and cores. A sandwich panel has two face sheets, top (or upper) and bottom (or lower) and a core. Each sandwich panel has a unique ID that facilitates its analyses for multiple load cases. Sandwich panel analysis uses middle surface as reference plane. Additional sandwich panels can be added by simply clicking the '+' sign on the extreme right (see below):

Sandwich Panels

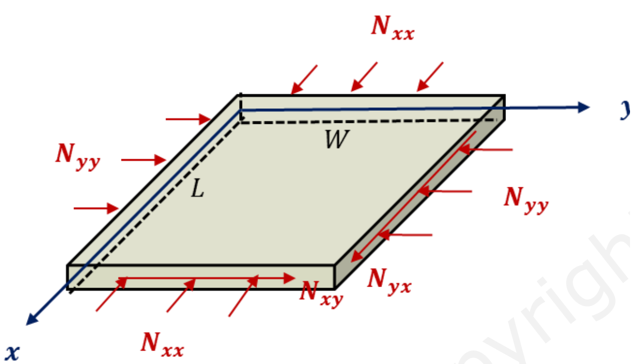
ID	Length	Width	Bottom Facesheet	Core	Top Facesheet	
1	15	10	1	1	1	+ −
2	15	10	1	2	1	+ −
3	15	10	1	3	1	+ −



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 sandwich panels (see figures below).



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	+	−

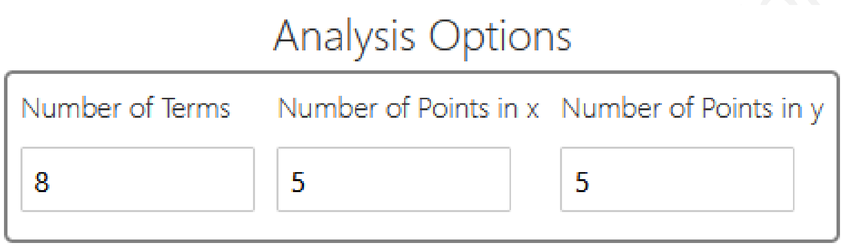
Inputs: Analysis Options

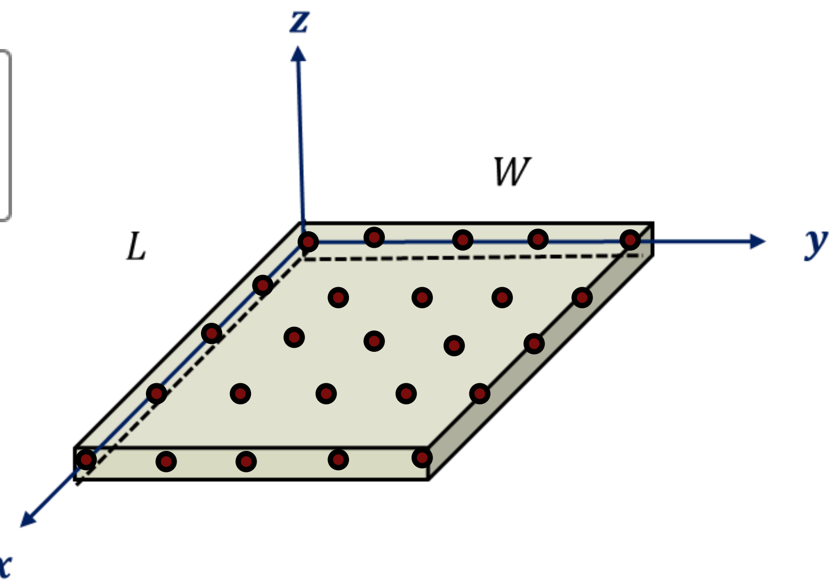
❖ Analysis Options:

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:





Outputs

❖ Analysis Outputs:

Once all the Input steps viz., Materials, Plies / Laminae, Cores, 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

3pc-solver008, v1.0b0

LOADS ID PANEL ID
1 1

PANEL GEOMETRY
LENGTH: 0.20
WIDTH : 0.90

ANALYSIS OPTIONS
m = 4
n = 4

OUTPUT OPTIONS
NUMBER OF POINTS IN X DIR: 11
NUMBER OF POINTS IN Y DIR: 11

MATERIAL PROPERTIES

ID	E1	E2	G12	G23	G13	v12	rho
Kollar0	1.48e+11	9.65e+09	4.55e+09	0.00e+00	0.00e+00	0.3000	0.05744239
iso	1.00e+02	1.00e+02	1.00e+02	7.69e+08	7.69e+08	0.3000	0.05744239

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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 Face sheet Laminate Information
- Face sheet Laminates and Sandwich Plate [A], [B], [D] stiffness matrices
- First Five (or lowest five) natural frequencies of vibration
- Grid Points coordinates x and y, and transverse displacements w for the first five modes of vibration

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

- Facesheet Laminate/Sandwich Plate [A] stiffness matrices N/m or N/mm or lb/in
- Facesheet Laminate/Sandwich Plate[B] stiffness matrices N-m/m or N-mm/mm or lb-in/in
- Facesheet Laminate/Sandwich Plate [D] stiffness matrices N-m or 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-solver008, v1.0b0

LOADS ID PANEL ID
1 1

PANEL GEOMETRY
LENGTH: 0.20
WIDTH : 0.90

ANALYSIS OPTIONS
m = 4
n = 4

OUTPUT OPTIONS
NUMBER OF POINTS IN X DIR: 11
NUMBER OF POINTS IN Y DIR: 11

MATERIAL PROPERTIES

ID	E1	E2	G12	G23	G13	v12	rho
Kollar0	1.48e+11	9.65e+09	4.55e+09	0.00e+00	0.00e+00	0.3000	0.05744239
iso	1.00e+02	1.00e+02	1.00e+02	7.69e+08	7.69e+08	0.3000	0.05744239

BOTTOM FACESHEET LAMINATE GEOMETRY
STACKING SEQUENCE (PLY ANG): [+45.0 , -45.0 , +45.0 , -45.0 , +0.0 , +0.0 , +0.0 , +0.0 , +0.0 , +0.0 , +0.0 , +0.0 , +0.0 , +0.0 , +0.0 , +0.0 , -45.0 , +45.0 , -45.0 , +45.0]
STACKING SEQUENCE (PLY MAT): [Kollar0 , Kollar0 , Kollar0 , Kollar0 , Kollar0 , Kollar0 , Kollar0 , Kollar0 , Kollar0 , Kollar0 , Kollar0 , Kollar0 , Kollar0 , Kollar0 , Kollar0 , Kollar0 , Kollar0 , Kollar0 , Kollar0 , Kollar0]
TOTAL THICKNESS: 0.0020
TOTAL MASS: 2.0679e-05

CORE GEOMETRY
CORE ANG: +0.0
CORE MAT: iso
THICKNESS: 0.0200
MASS: 2.0679e-04

Output Text

```
TOP FACESHEET LAMINATE GEOMETRY
STACKING SEQUENCE (PLY ANG): [+45.0        , -45.0        , +45.0        , -45.0        , +0.0         , +0.0         , +0.0
, +0.0         , +0.0         , +0.0         , +0.0         , +0.0         , +0.0         , +0.0         , +0.0         , +0.0         , -
45.0         , +45.0        , -45.0        , +45.0        ]
STACKING SEQUENCE (PLY MAT): [Kollar0      , Kollar0      , Kollar0      , Kollar0      , Kollar0      , Kollar0      , Kollar0
, Kollar0      , Kollar0      , Kollar0      , Kollar0      , Kollar0      , Kollar0      , Kollar0      , Kollar0      , Kollar0      ,
Kollar0      , Kollar0      , Kollar0      , Kollar0      ]
TOTAL THICKNESS: 0.0020
TOTAL MASS: 2.0679e-05

   BOTTOM FACESHEET LAMINATE PROPERTIES
                A MATRIX
+215169305.42 +32735460.05  +0.00
+32735460.05  +48169308.82  +0.00
+0.00         +0.00         +36011282.36

                B MATRIX
-0.00         -0.00         +0.00
-0.00         +0.00         +0.00
+0.00         +0.00         +0.00

                D MATRIX
+45.30        +19.52        +2.23
+19.52        +25.26        +2.23
+2.23         +2.23         +20.62

    TOP FACESHEET LAMINATE PROPERTIES
                A MATRIX
+215169305.42 +32735460.05  +0.00
+32735460.05  +48169308.82  +0.00
+0.00         +0.00         +36011282.36

                B MATRIX
-0.00         -0.00         +0.00
-0.00         +0.00         +0.00
+0.00         +0.00         +0.00
```

Output Text

D MATRIX

+45.30	+19.52	+2.23
+19.52	+25.26	+2.23
+2.23	+2.23	+20.62

SANDWICH PLATE PROPERTIES

TOTAL THICKNESS: 0.0240

A MATRIX

+430338613.03	+65470920.75	+0.00
+65470920.75	+96338619.83	+0.00
+0.00	+0.00	+72022566.71

A MATRIX - TRANSVERSE SHEAR

+15384615.38	+0.00
+0.00	+15384615.38

B MATRIX

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

D MATRIX

+52161.57	+7961.03	+4.45
+7961.03	+11707.49	+4.45
+4.45	+4.45	+8755.96

EFFECTIVE BOTTOM FACESHEET LAMINATE INPLANE AND FLEXURAL ENGINEERING CONSTANTS

Ex Ey Gxy vxy vyx Efx Efy Gfxy vfxy vfyx

+9.65e+10 +2.16e+10 +1.80e+10 +0.6796 +0.1521 +4.53e+10 +2.51e+10 +3.06e+10 +0.7708
+0.4280

EFFECTIVE TOP FACESHEET LAMINATE INPLANE AND FLEXURAL ENGINEERING CONSTANTS

Ex Ey Gxy vxy vyx Efx Efy Gfxy vfxy vfyx

+9.65e+10 +2.16e+10 +1.80e+10 +0.6796 +0.1521 +4.53e+10 +2.51e+10 +3.06e+10 +0.7708
+0.4280

Output Text

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

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
0.0500	0.0000	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00
0.1000	0.0000	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00
0.1500	0.0000	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00
0.2000	0.0000	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00
0.0000	0.2250	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00
0.0500	0.2250	+5.0000e-01	+7.0710e-01	-4.9990e-01	+7.0720e-01	-1.0001e+00
0.1000	0.2250	+7.0710e-01	+1.0000e+00	-7.0710e-01	+1.0000e-04	-2.0000e-04
0.1500	0.2250	+5.0000e-01	+7.0710e-01	-5.0010e-01	-7.0700e-01	+9.9990e-01
0.2000	0.2250	+0.0000e+00	+0.0000e+00	-0.0000e+00	-0.0000e+00	+0.0000e+00
0.0000	0.4500	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00
0.0500	0.4500	+7.0710e-01	-0.0000e+00	+7.0710e-01	+1.0000e+00	+3.0000e-04
0.1000	0.4500	+1.0000e+00	+0.0000e+00	+1.0000e+00	+0.0000e+00	+3.0000e-04
0.1500	0.4500	+7.0710e-01	+0.0000e+00	+7.0710e-01	-1.0000e+00	+3.0000e-04
0.2000	0.4500	+0.0000e+00	+0.0000e+00	+0.0000e+00	-0.0000e+00	+0.0000e+00
0.0000	0.6750	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00
0.0500	0.6750	+5.0000e-01	-7.0710e-01	-5.0010e-01	+7.0700e-01	+9.9990e-01
0.1000	0.6750	+7.0710e-01	-1.0000e+00	-7.0710e-01	-1.0000e-04	-2.0000e-04
0.1500	0.6750	+5.0000e-01	-7.0710e-01	-4.9990e-01	-7.0720e-01	-1.0001e+00
0.2000	0.6750	+0.0000e+00	-0.0000e+00	-0.0000e+00	-0.0000e+00	-0.0000e+00
0.0000	0.9000	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00
0.0500	0.9000	+0.0000e+00	-0.0000e+00	-0.0000e+00	+0.0000e+00	+0.0000e+00
0.1000	0.9000	+0.0000e+00	-0.0000e+00	-0.0000e+00	+0.0000e+00	+0.0000e+00
0.1500	0.9000	+0.0000e+00	-0.0000e+00	-0.0000e+00	-0.0000e+00	-0.0000e+00
0.2000	0.9000	+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, Face sheet laminates, Sandwich Panels and Loads data files (*.jso 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:

Materials

E1 E2 G12 G23 G13 v12 α1 α2 β1

ID	v21
GMS4020 PW	0.05
GMS4020 Tape	0.0254
2024-T3	0.3
Rastogi_Fiberglass	0.02667
Tuttle	0.01662

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

General Information

- Subscription fee to access 3pcsolver008 is $39/year per for a single-login license

- Training module 3pcmodule008 supports the solver 3pcsolver008. 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 3pcsolver008 and 3pcmodule008. 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: Free Vibrations of Sandwich Plates

- Lamina Properties: $E_1 = 1.68e7\,psi, E_2 = 1.16e6\,psi, G_{12} = 8.0e5\,psi, \nu_{21} = 0.35$, $t_{ply} = 0.00525\,inch, \rho = 1.49 \times 10^{-4}\text{lb} - \text{sec}^2/\text{in}^4$

- Core Properties: $E_1 = E_2 = 1000\,psi, G_{12} = 10\,psi, G_{13} = 13000\,psi, G_{23} = 6000\,psi, \nu_{21} = 0.1, t_{core} = 0.5\,inch$, $\rho = 4.66 \times 10^{-6}\text{lb} - \text{sec}^2/\text{in}^4$

- Plate Dimensions: L = 15 in., W = 10 in., Aspect Ratio $\frac{L}{W} = 1.5$

- Bottom Facesheet Laminate: $[0/90/\pm 45/0/90]_T$

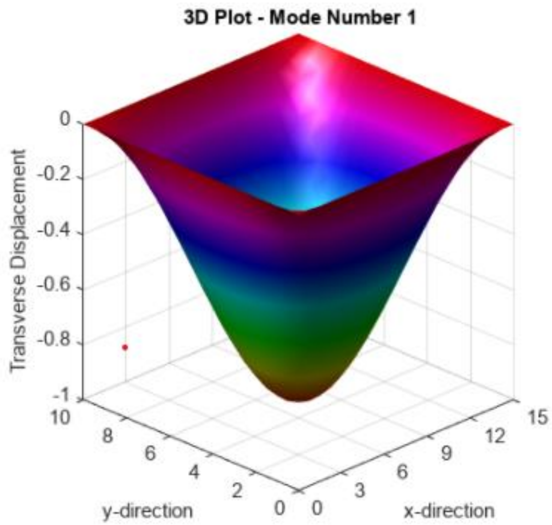
- Top Facesheet Laminate: $[90/0/\mp 45/90/0]_T$

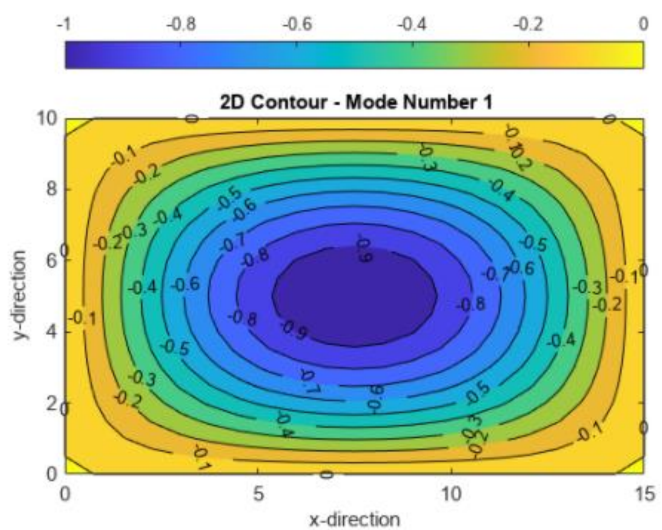
- Load Cases:
  - I: No Edge Loadings
  - II: Applied Axial Edge Compression, N_{xx} = -1000 lb/in

- MATLAB scripts are used to plot transverse displacement w of the sandwich plates for different mode shapes

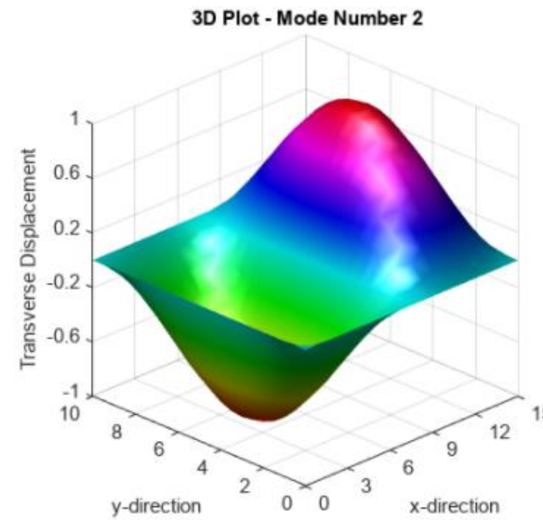
Case I: Frequencies and Mode Shapes of Sandwich Plate

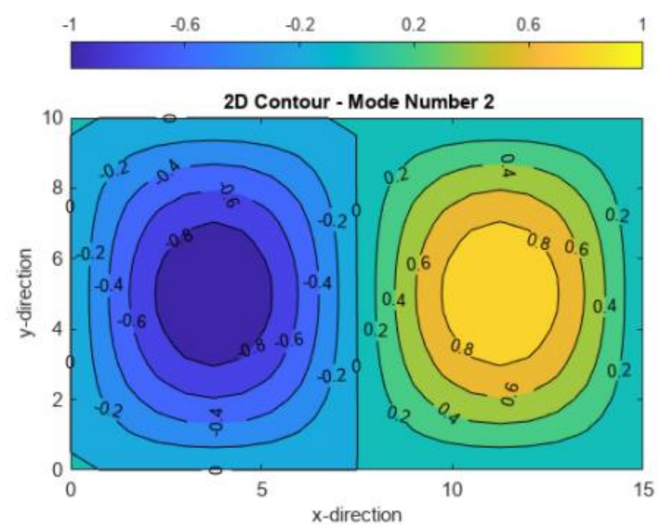
First Fundamental Frequency: 781 Hz





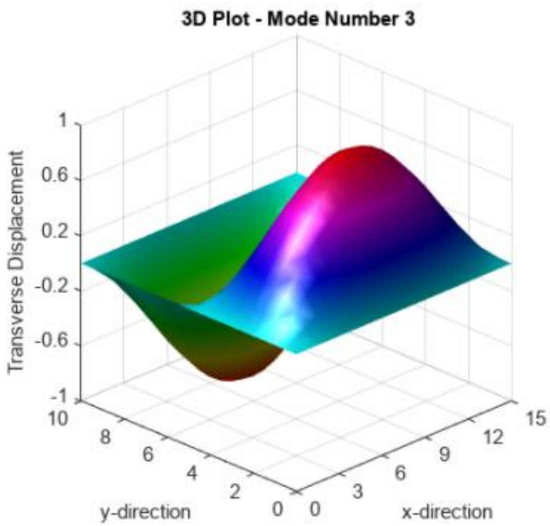
Second Fundamental Frequency: 1356 Hz

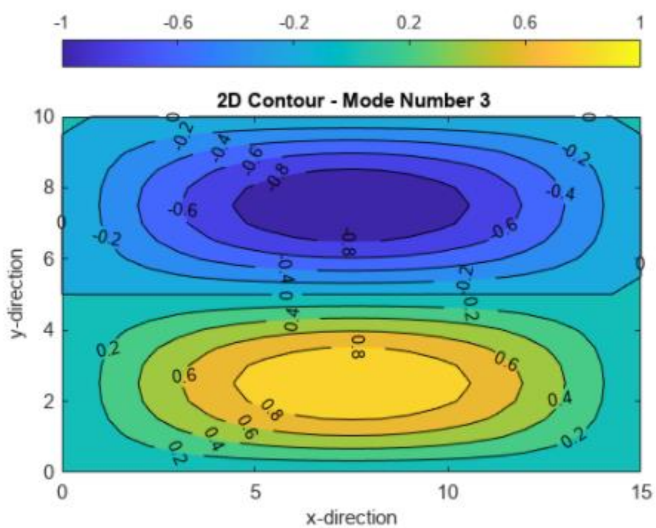




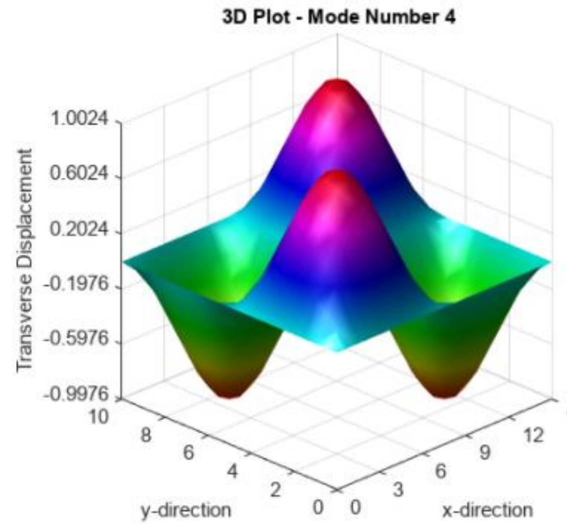
Case I: Frequencies and Mode Shapes of Sandwich Plate

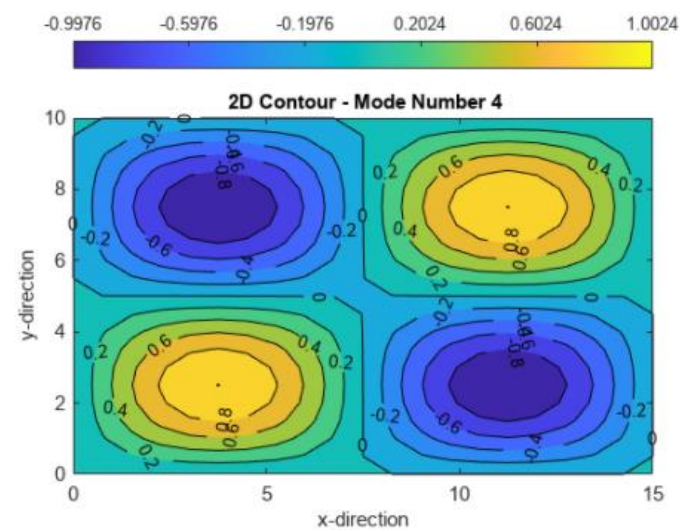
Third Fundamental Frequency: 1577 Hz





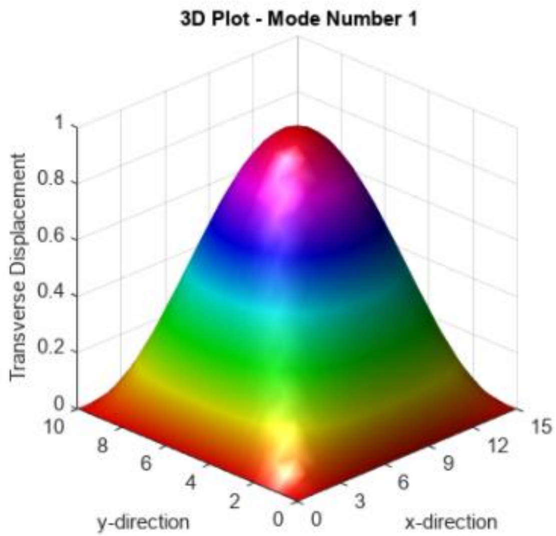
Fourth Fundamental Frequency: 1974 Hz

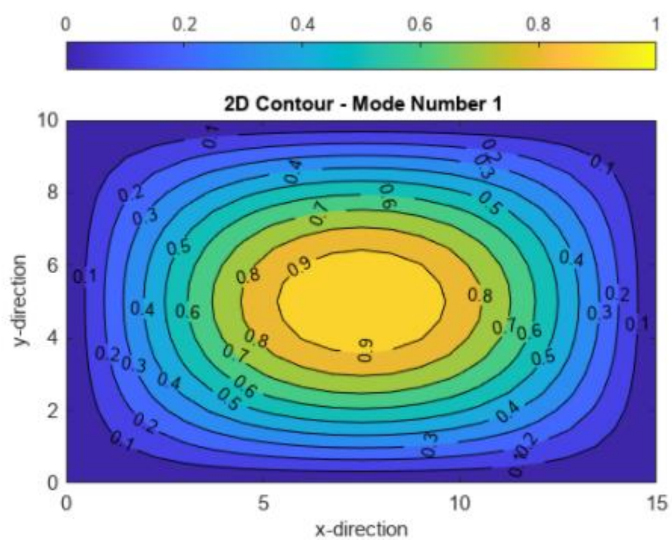




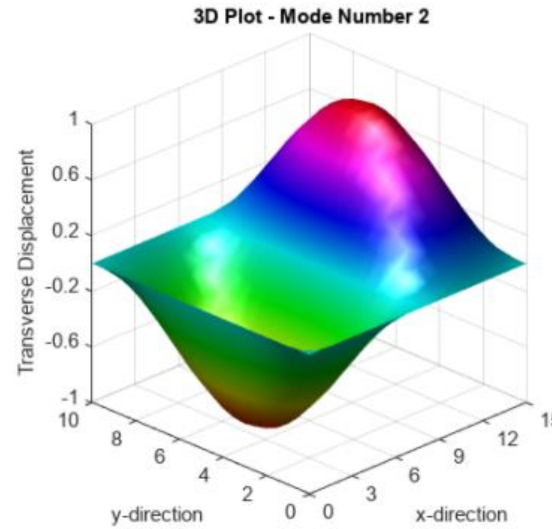
Case II: Frequencies and Mode Shapes of Sandwich Plate

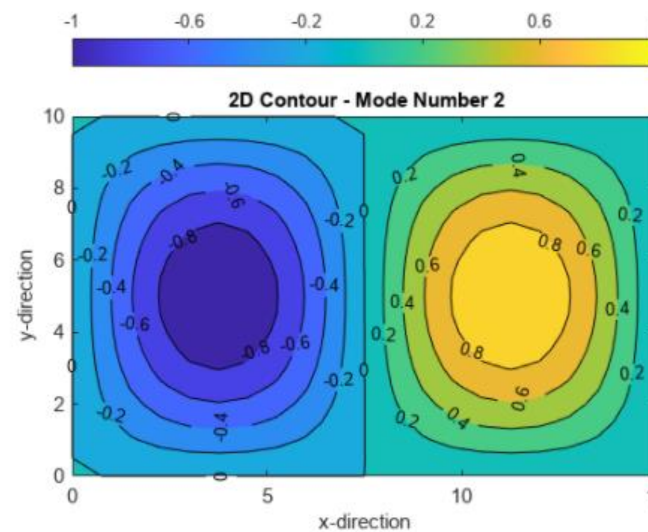
First Fundamental Frequency: 718 Hz





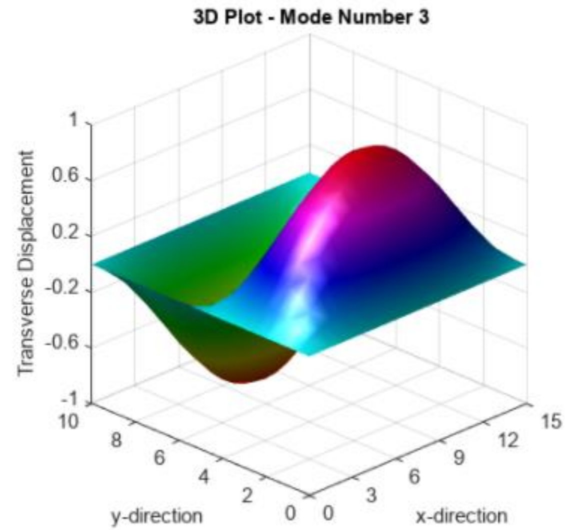
Second Fundamental Frequency: 1208 Hz

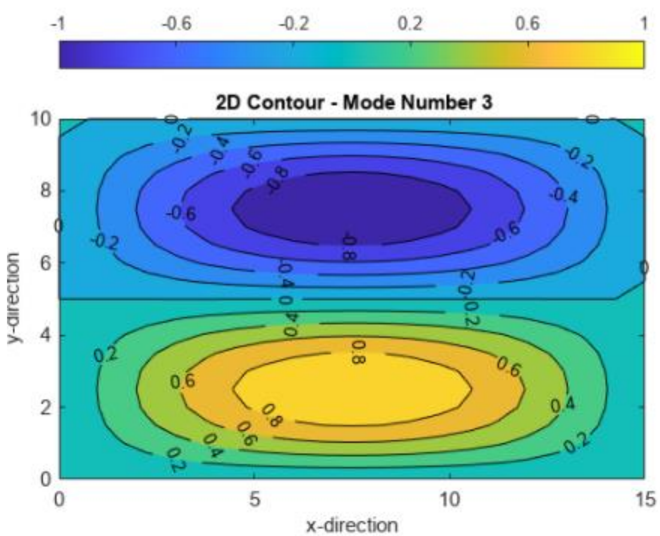




Case II: Frequencies and Mode Shapes of Sandwich Plate

Third Fundamental Frequency: 1547 Hz





Fourth Fundamental Frequency: 1865 Hz