3PC SOLVER 007

Buckling Analysis of Simply-Supported Sandwich Composite Plates

1/30/2023

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Contents: 3pcsolver007

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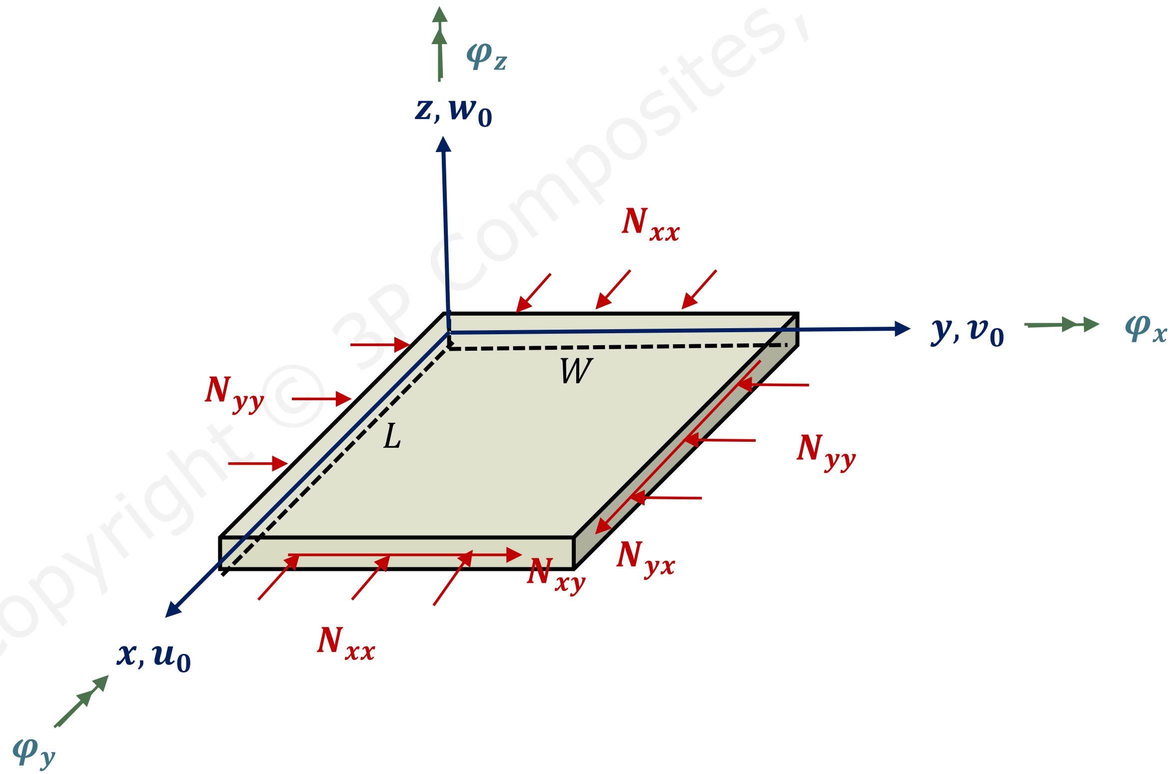
Overview

❖ 3pcsolver007 performs **linear** elastic global buckling analysis of simply-supported sandwich plates subjected combined in-plane edge compression/tension and/or edge shear loads. Simply-supported boundary condition is most widely used in the analysis of plates and shells. Applied compressive bi-axial loads and positive shear load is shown below:



Overview

❖ Following combinations of in-plane buckling loads can be analyzed using the solver 3pcsolver007:

- ✓ Longitudinal Compression N_{xx}
- ✓ Lateral Compression N_{yy}
- ✓ In-plane Shear N_{xy}
- ✓ Bi-axial Compression N_{xx} and N_{yy}
- ✓ Longitudinal Compression N_{xx} and Lateral Tension N_{yy}
- ✓ Longitudinal Tension N_{xx} and Lateral Compression N_{yy}
- ✓ Longitudinal Compression N_{xx} and In-plane Shear N_{xy}
- ✓ Longitudinal Tension N_{xx} and In-plane Shear N_{xy}
- ✓ Lateral Compression N_{yy} and In-plane Shear N_{xy}
- ✓ Lateral Tension N_{yy} and In-plane Shear N_{xy}
- ✓ Longitudinal Compression N_{xx}, Lateral Tension N_{yy} and In-plane Shear N_{xy}
- ✓ Longitudinal Tension N_{xx}, Lateral Compression N_{yy} and In-plane Shear N_{xy}
- ✓ Longitudinal and Lateral Tensions N_{xx} & N_{yy} and In-plane Shear N_{xy}
- ✓ Bi-axial Compression N_{xx} & N_{yy} and In-plane Shear N_{xy}

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

- **3pcsolver007** 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. Principle of virtual work and Ritz analysis procedure are used to obtain a highly coupled system of algebraic equations for linear elastic buckling analyses of sandwich plates (see below):

$$\begin{bmatrix} K_{11} & K_{12} & 0 & K_{14} & K_{15} \\ K_{21} & K_{22} & 0 & K_{24} & K_{25} \\ 0 & 0 & K_{33}+\lambda_{mn}F_{33} & K_{34} & K_{35} \\ K_{14} & K_{42} & K_{43} & K_{44} & K_{45} \\ K_{51} & K_{25} & K_{53} & K_{54} & K_{55} \end{bmatrix} \begin{Bmatrix} u_{mn} \\ v_{mn} \\ w_{mn} \\ \varphi_{xmn} \\ \varphi_{ymn} \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{Bmatrix}$$

- 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. It is assumed that the edge loads can be expressed as $N_{xx}^0 = \lambda N_{xx}^0$, $N_{yy}^0 = \lambda N_{yy}^0$ and $N_{xy}^0 = \pm\lambda N_{xy}^0$ (where λ is the critical buckling factor, $0 < N_{xx}^0, N_{yy}^0$). F_{33} term contain information about the total applied edge loads from mechanical loadings

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 global buckling load factors λ_{mn} for a simply-supported sandwich plates subjected to various combinations of applied compression/tension and/or edge shear loads

$$\begin{vmatrix} K_{11} & K_{12} & 0 & K_{14} & K_{15} \\ K_{21} & K_{22} & 0 & K_{24} & K_{25} \\ 0 & 0 & K_{33} + \lambda_{mn} F_{33} & K_{34} & K_{35} \\ K_{14} & K_{42} & K_{43} & K_{44} & K_{45} \\ K_{51} & K_{25} & K_{53} & K_{54} & K_{55} \end{vmatrix} = \{0\}$$

- 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. The buckling mode shapes for each buckling factor λ_{mn} can be obtained by substituting the λ_{mn} in the system of equations given on the previous slide

- Given the lamina/ply and core material properties, sandwich plate construction and its length and width dimensions, 3pcsolver007 solver calculates buckling load factors for a sandwich plate subjected to any combination of the load described on Slide 6

3P COMPOSITES PRODUCIBILITY PERFORMANCE PROFITABILITY

Theoretical Background

- The 3pcsolver007 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 obtain buckling load factors for sandwich plates subjected to combined edge compression/tension and shear loads with various types of factsheets and cores. In case of laminated composite factsheets, 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 buckling 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. Examples are solved using **3pcsolver007** solver, and results are compared with those (i) obtained from standard commercially available finite element analysis software, and (ii) available in open literature

3P COMPOSITES PRODUCIBILITY PERFORMANCE PROFITABILITY

Theoretical Background

- Many different types of ply and core material systems, ply orientations, facesheet 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. Numerical examples highlight the adverse effects of face sheet laminate stiffness couplings on buckling of sandwich plates with laminated composites face sheets

- Details of the theoretical approach along with numerous verification and application examples are available in the training module **3pcmodule007**

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. 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}		
aiaa-2009	18000000	1600000	870000	640000	870000	0.3	+	−
CPW	9040000	9040000	720000	7	7	0.046	+	−
Ncore	1000	1000	10	6000	13000	0.1	+	−
Ncore2	1000	1000	10	13000	6000	0.1	+	−

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 Facesheet 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		
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	+	–

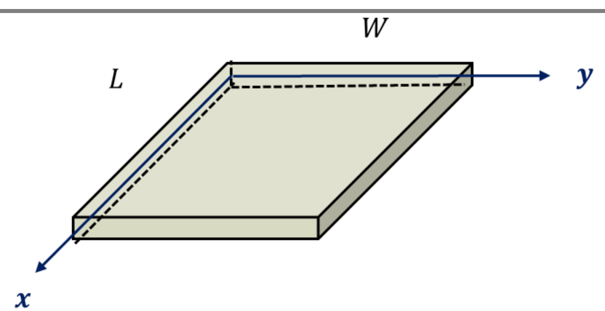
Inputs: Sandwich Panels

❖ Sandwich Panels:

Sandwich Panels are defined by its Length and width dimensions and the definitions of facesheet 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

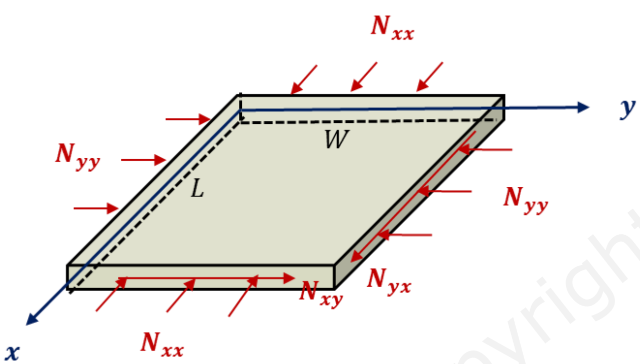
ID	Length	Width	Bottom Facesheet	Core	Top Facesheet		
1	15	10	1	1	1	+	–
2	15	10	1	2	1	+	–
3	15	10	1	3	1	+	–



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	-1	0	0
2	2	-1	0	0
3	1	-1	-0.473	0
4	2	-1	-0.473	0
5	1	-1	15.6563	0
6	2	-1	15.6563	0
7	1	0	-1	0
8	2	0	-1	0

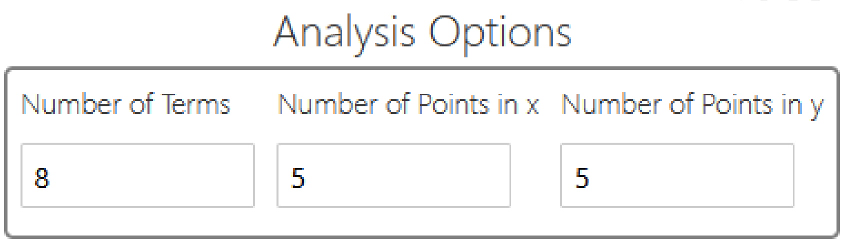
Inputs: Analysis Options

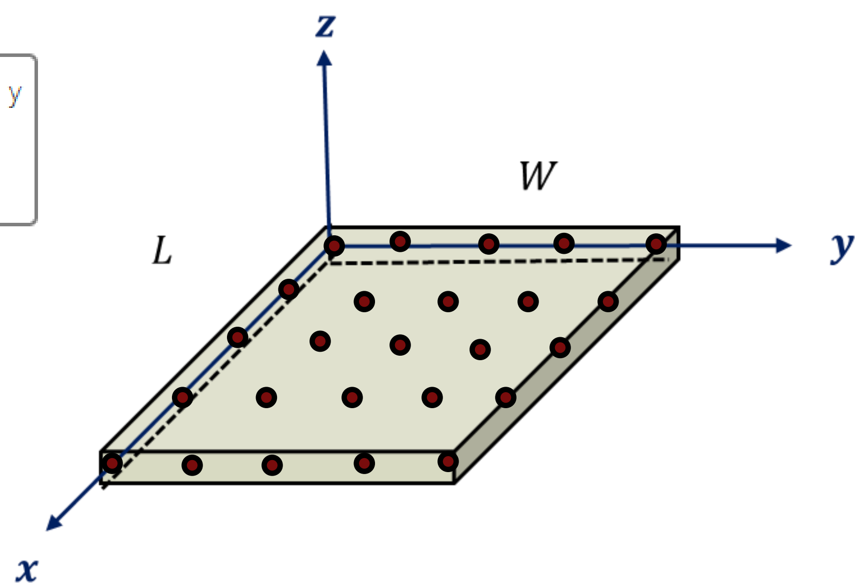
❖ Analysis Options:

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, Sandwich 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-solver007, v1.0b0

LOADS ID   PANEL ID
1          1

PANEL GEOMETRY
LENGTH: 0.20
WIDTH : 0.90

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
Kollar0       1.48e+11      9.65e+09      4.55e+09      0.00e+00      0.00e+00      0.3000
```

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) critical buckling loads
- Grid Points coordinates x and y, and transverse displacements w for first five critical buckling loads

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
- Transverse Displacements in mm, m or in and Rotations in 1/mm, 1/m or 1/in

A typical output is shown below:

Output Text

```
3pc-solver007, v1.0b0

LOADS ID  PANEL ID
1         1

PANEL GEOMETRY
LENGTH: 0.20
WIDTH : 0.90

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
Kollar0     1.48e+11    9.65e+09    4.55e+09    0.00e+00    0.00e+00    0.3000
iso         1.00e+02    1.00e+02    1.00e+02    7.69e+08    7.69e+08    0.3000

   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

      CORE GEOMETRY
CORE ANG: +0.0
CORE MAT: iso
THICKNESS: 0.0200
```

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

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

3P COMPOSITES PRODUCIBILITY PERFORMANCE PROFITABILITY

Output Text

APPLIED LOADS CRITICAL LOADS

NUMBER	NXX	NYY	NXY	NXXCR	NYYCR	NXYCR
1	-1.0000	0.0000	0.0000	-22.1208	0.0000	0.0000
2	-1.0000	0.0000	0.0000	-22.5359	0.0000	0.0000
3	-1.0000	0.0000	0.0000	-26.2087	0.0000	0.0000
4	-1.0000	0.0000	0.0000	-31.7513	0.0000	0.0000
5	-1.0000	0.0000	0.0000	-36.0108	0.0000	0.0000

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

Other Features

❖ Upload/Download:

Users can upload and download Material properties, Plies, Laminates, Cores, 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

E_1 E_2 G_{12} G_{23} G_{13} ν_{12} α_1 α_2 β_1

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

General Information

- Subscription fee to access 3pcsolver007 is $39/year per for a single-login license

- Training module 3pcmodule007 supports the solver 3pcsolver007. 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 3pcsolver007 and 3pcmodule007. The training can be adapted to meet the requirements of individual needs and/or industrial applications

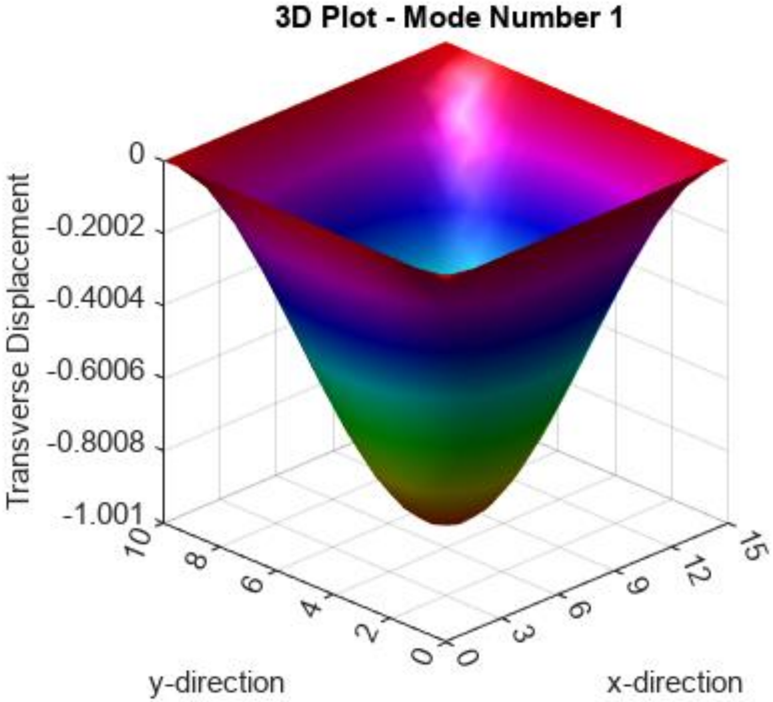
- For questions, issues, comments, suggestions, trainings, please contact us at 3pcomps@gmail.com. Your feedback is appreciated in helping us continuously improve the product

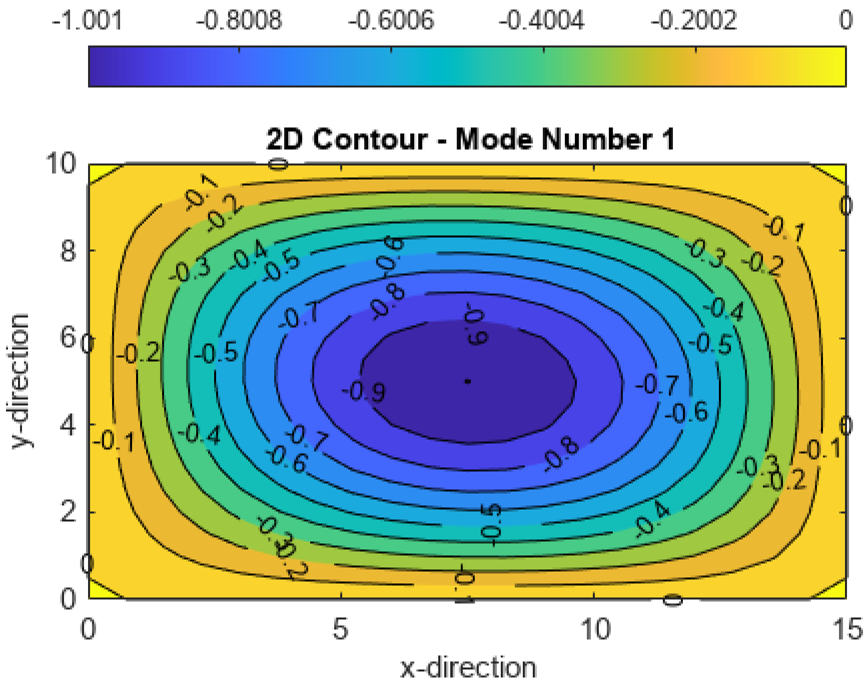
Example: Global Buckling of Sandwich Plates

- Lamina Properties: $E_1 = 1.68e7\,psi, E_2 = 1.16e6\,psi, G_{12} = 8.0e5\,psi, \nu_{21} = 0.35, t_{ply} = 0.00525\,inch$
- Core Properties: $E_1 = E_2 = 1000\,psi, G_{12} = 10\,psi, G_{13} = 13000\,psi, G_{23} = 6000\,psi, \nu_{21} = 0.1, t_{core} = 0.5\,inch$
- Plate Dimensions: L = 15 in., W = 10 in., Aspect Ratio $\frac{L}{W} = 1.5$
- Bottom Facesheet Laminate: $[0/90/\pm45/0/90]_T$
- Top Facesheet Laminate: $[90/0/\mp45/90/0]_T$
- Load Case: Applied Bi-Axial Edge Compression and shear, N_{xx} = -1000 lb/in and N_{yy} = -500 lb/in, N_{xy} = 50 lb/in
- MATLAB scripts are used to plot transverse displacement w of the sandwich plates for different mode shapes

Sandwich Plate Buckling Mode Shape I

Buckling Factor: 3.02

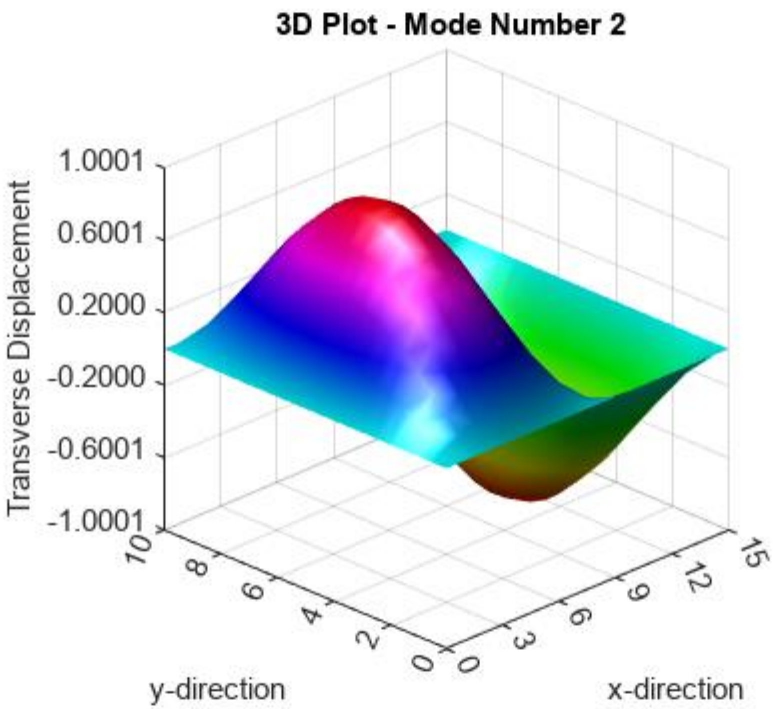


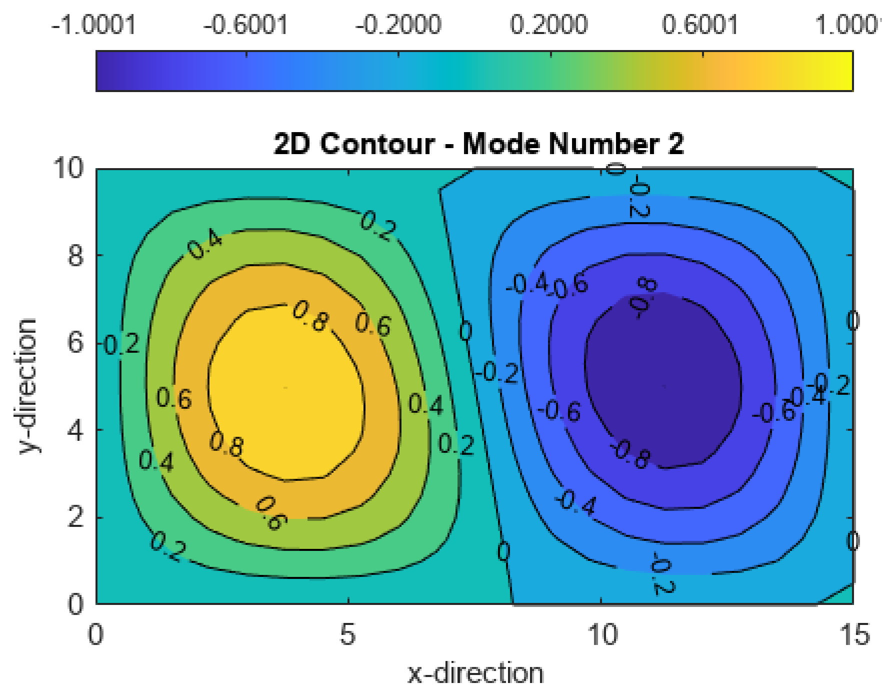


NUMBER	NXX	NYY	NXY	NXXCR	NYYCR	NXYCR
1	-1000.0000	-500.0000	50.0000	-3023.7969	-1511.8985	151.1898

Sandwich Plate Buckling Mode Shape II

Buckling Factor: 3.77

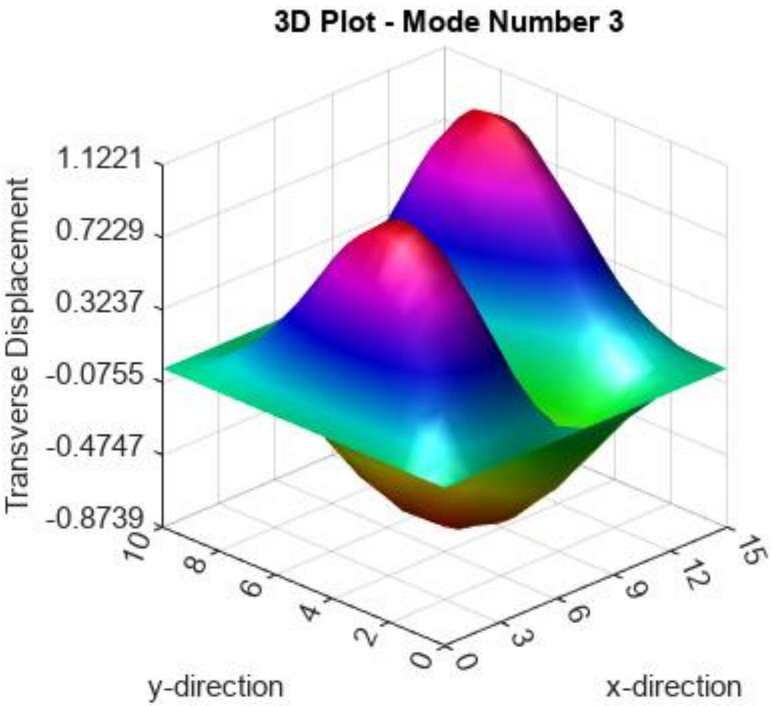


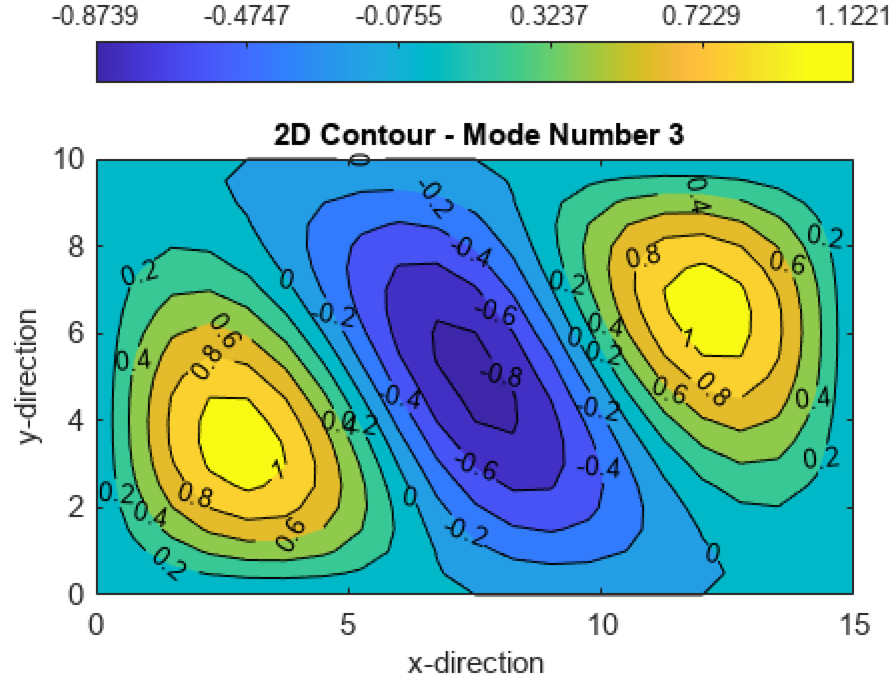


NUMBER	NXX	NYY	NXY	NXXCR	NYYCR	NXYCR
2	-1000.0000	-500.0000	50.0000	-3768.7226	-1884.3613	188.4361

Sandwich Plate Buckling Mode Shape III

Buckling Factor: 4.57

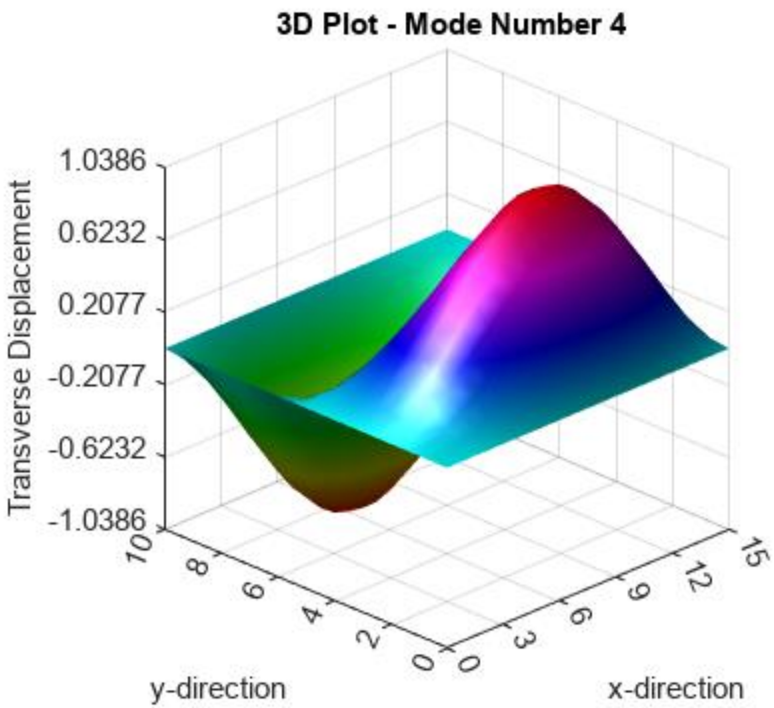


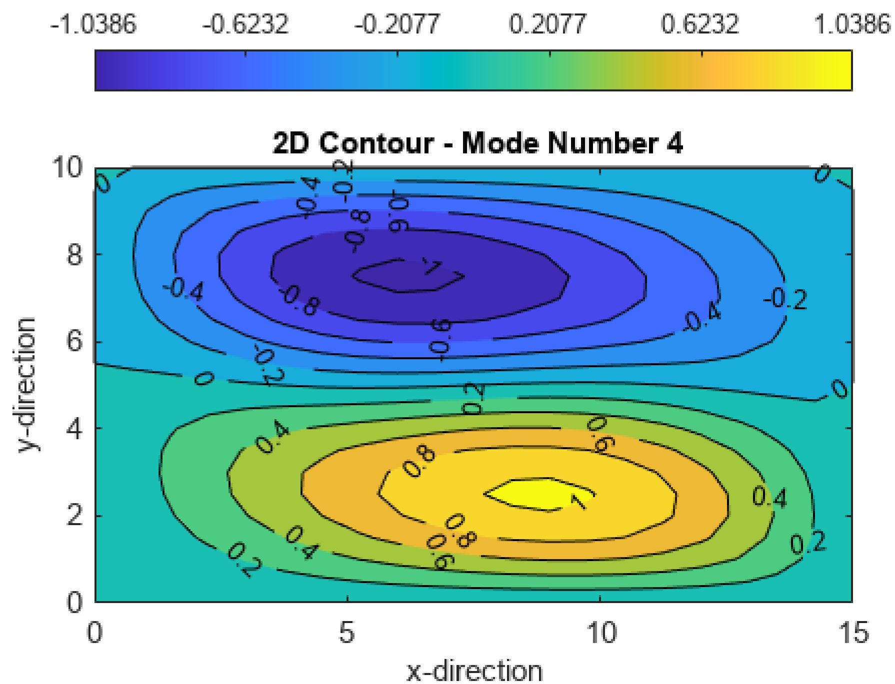


NUMBER	NXX	NYY	NXY	NXXCR	NYYCR	NXYCR
3	-1000.0000	-500.0000	50.0000	-4569.9741	-2284.9870	228.4987

Sandwich Plate Buckling Mode Shape IV

Buckling Factor: 4.76

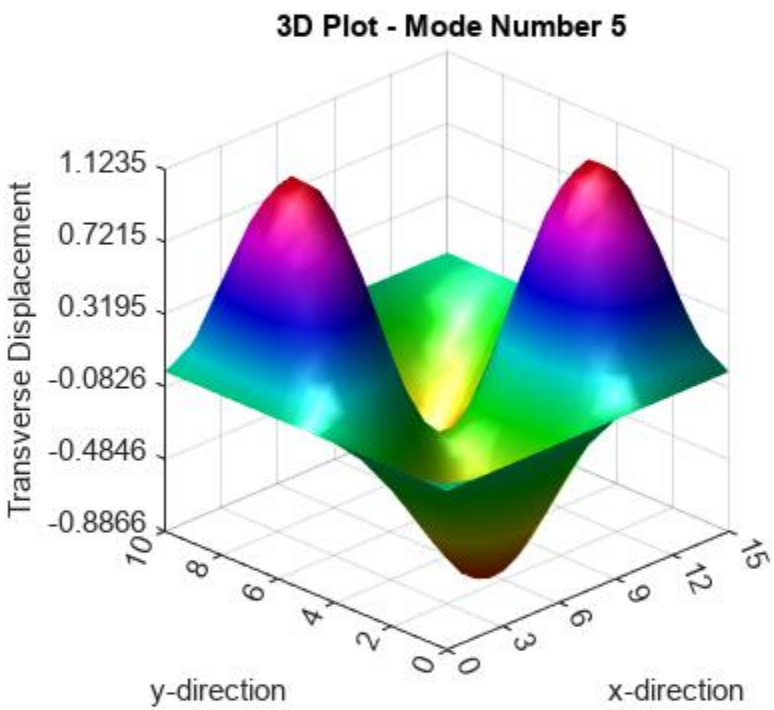


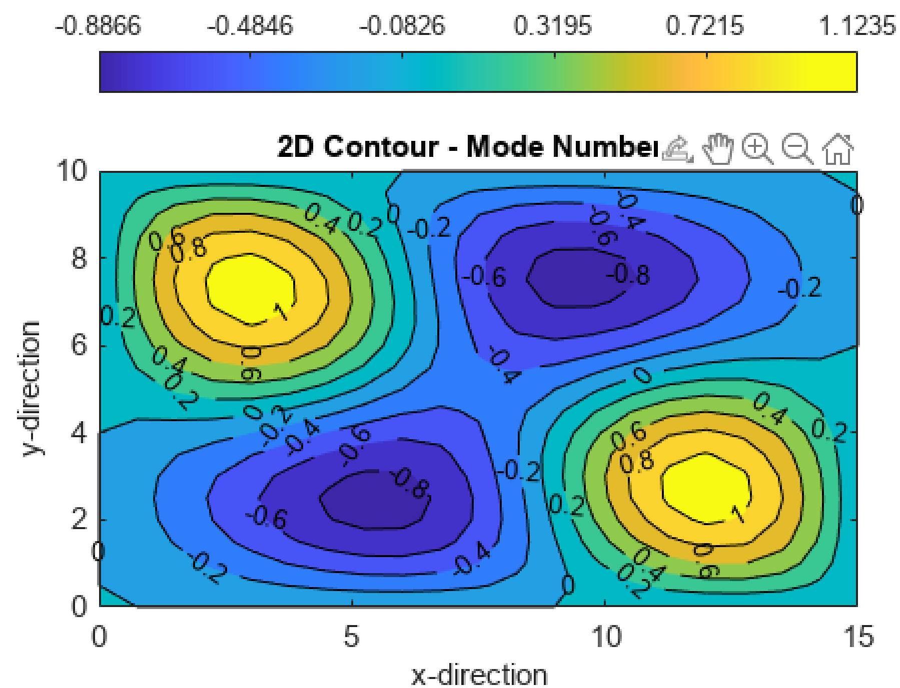


NUMBER	NXX	NYY	NXY	NXXCR	NYYCR	NXYCR
4	-1000.0000	-500.0000	50.0000	-4756.7137	-2378.3569	237.8357

Sandwich Plate Buckling Mode Shape V

Buckling Factor: 4.80





NUMBER	NXX	NYY	NXY	NXXCR	NYYCR	NXYCR
5	-1000.0000	-500.0000	50.0000	-4799.8044	-2399.9022	239.9902