3PC SOLVER006

Bending Analysis of Simply Supported Sandwich Composite Plates

1/30/2023

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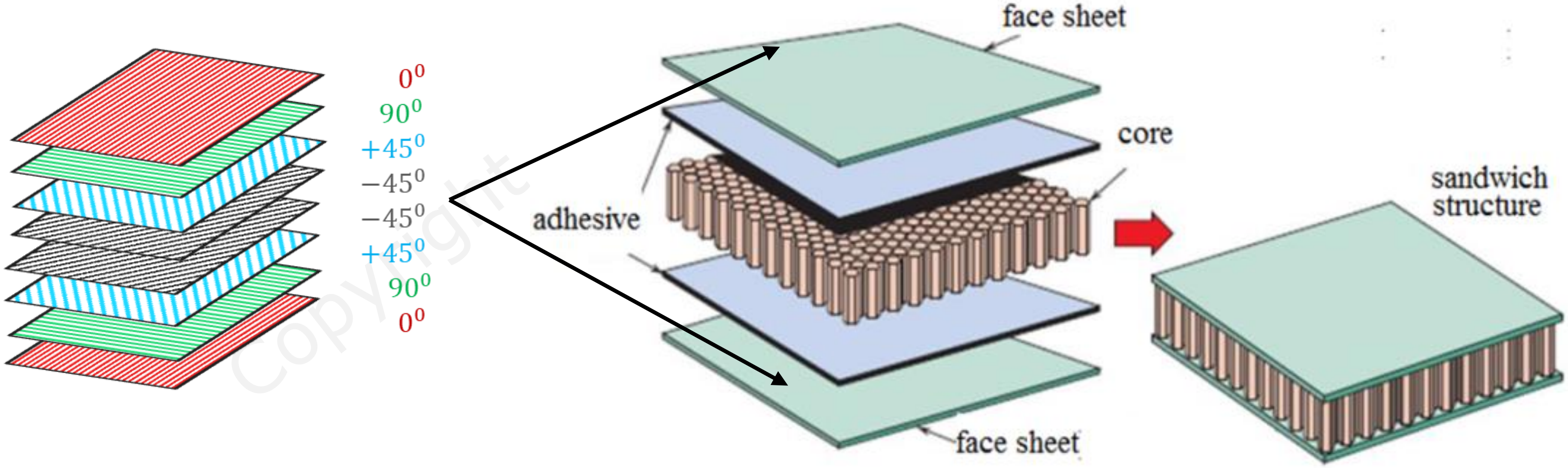
Contents: 3pcsolver006

Sandwich Structures

- Sandwich panels are generally the most efficient way of providing high flexural (or bending) stiffness at lowest weight to resist transverse normal loads due to pressure and/or concentrated force(s). They provide large increase in moment of inertia without weight penalty. Sandwich panels are also one of the most efficient ways to provide acoustic damping

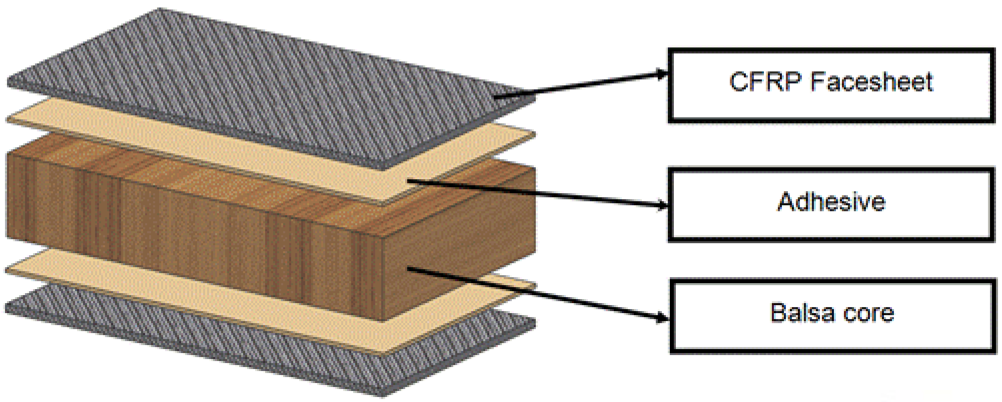
- The key components of a sandwich structure are the top and bottom facesheets, and a core that separates the two facesheets by an optimally designed distance and provides the required flexural stiffness. An adhesive layer is placed at the interfaces of the facesheets and the core to ensure good bond between them. A typical sandwich panel is shown below



Picture Reference:
"Analysis of Sandwich Structures by the FEM" **Peter Sivák, Ingrid Delyová, Patrícia Diabelková,** AJME, 2017, 5(6),243-246 doi:10.12691/ajme-5-6-2

Sandwich Structures

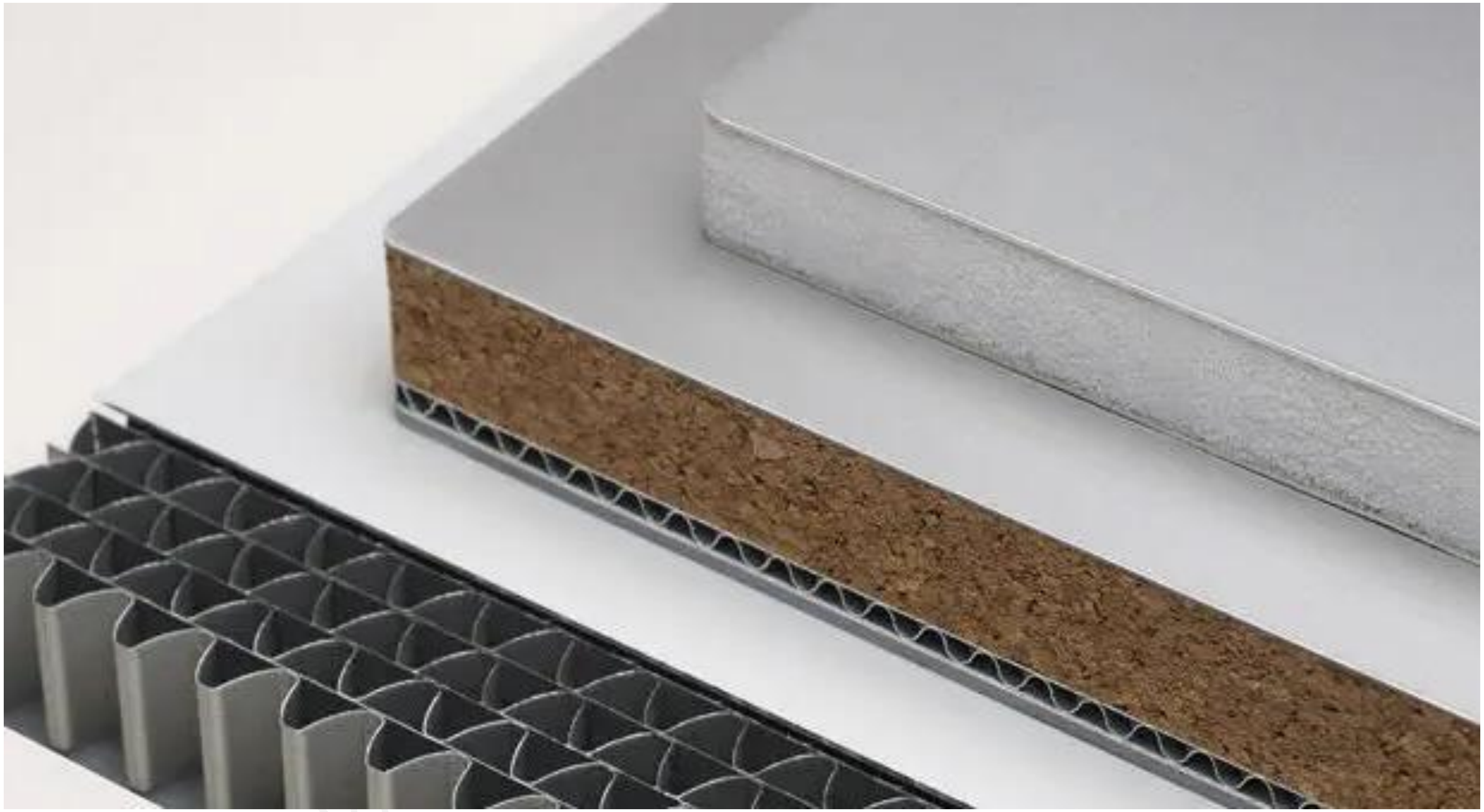
❖ The facesheets can be fabricated from metallic or composite materials. The core can be any metallic or non-metallic material. With many possible combinations. Sandwich structures offer numerous possibilities to design various structures for optimal performance for lightest weight and cost. A few examples of sandwich constructions are shown below:



Picture Reference:
https://www.researchgate.net/figure/The-CFRP-Balsa-sandwich-structure_fig1_317224037, DOI: 10.15376/biores.12.2.2673-2689

Picture Reference:
http://www.topolocfrt.com/pvc-foam-sandwich-panel/

Sandwich Structures



Picture Reference:
https://www.directindustry.com/prod/metawell-gmbh-metal-sandwich-technology/product-193280-1971936.html

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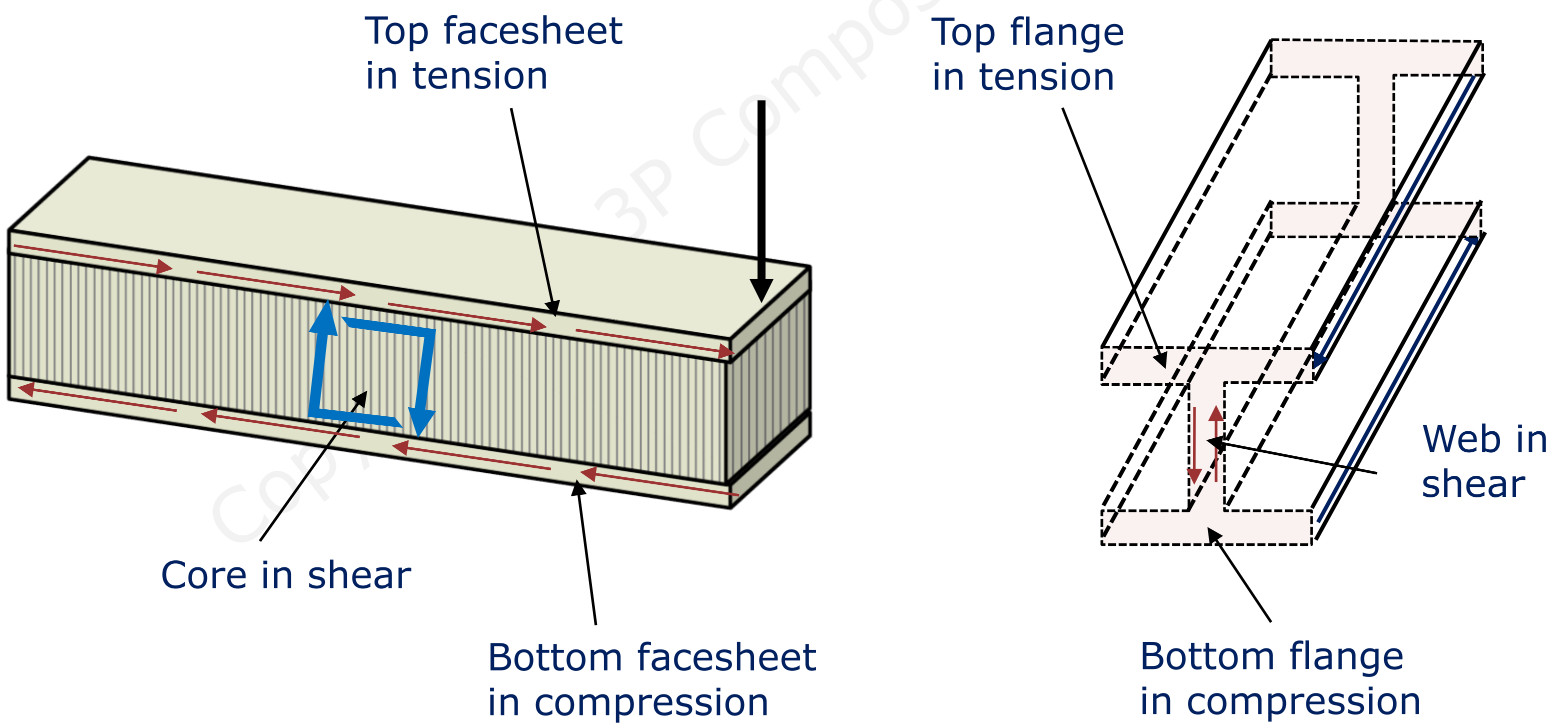
Sandwich Structures

Picture Reference:
https://aerospaceengineeringblog.com/sandwich-panel/

Picture Reference :
https://www.avient.com/products/advanced-composites/continuous-fiber-composite-panels

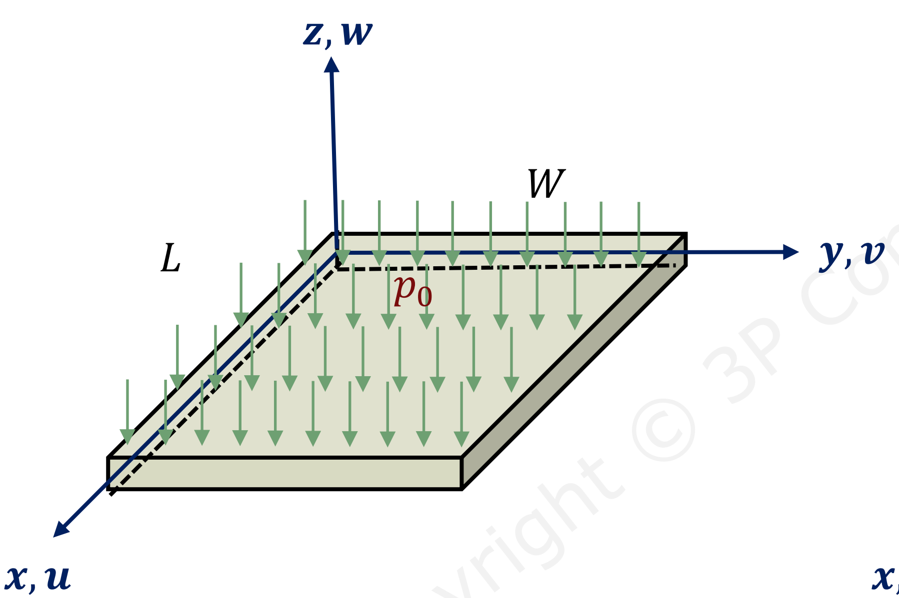
Analysis of Sandwich Structures

- Sandwich structures are analogous to traditional I-beams. In I-beams, beam flanges react the bending moment as axial tension and compression forces, and beam web resists the shear loads manifesting from the transverse bending. Sandwich structures behave very similar to I-beams in that the stiff/strong facesheets reacting the bending moment as axial tension and compression forces manifesting from the couple, and relatively less stiff or softer core resisting the transverse shear loads. A schematic comparison of the two is shown below:

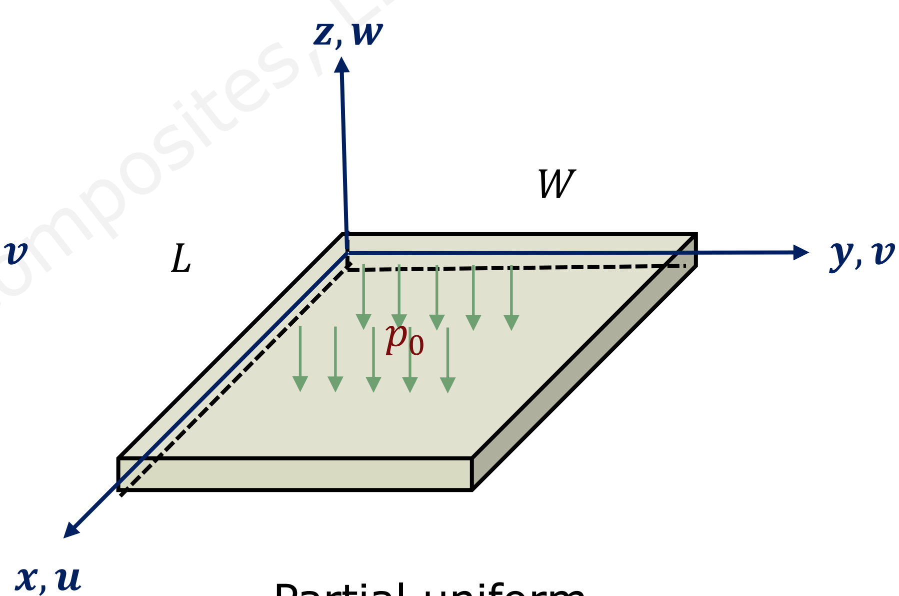


Solver Overview

❖ 3pcsolver006 performs bending analysis of simply-supported anisotropic composite sandwich panels subjected to transverse loads. Simply-supported boundary condition is most widely used in structural analysis. Four types of transverse loading as shown below are considered:

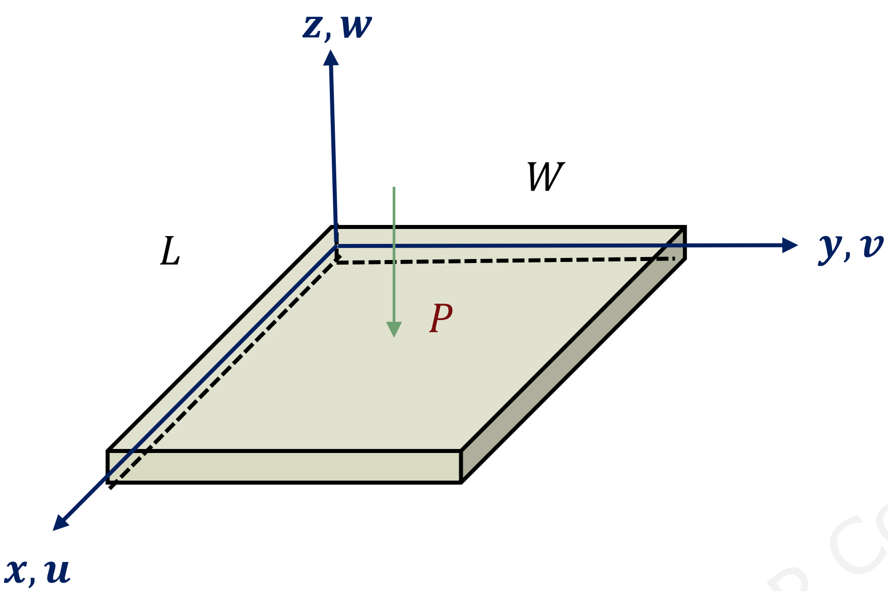


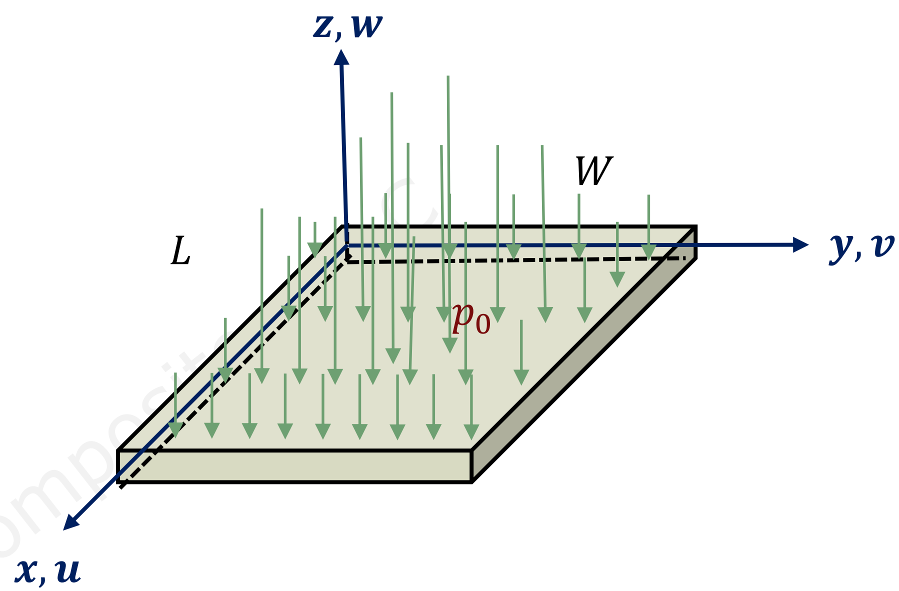
Uniform Pressure p_0



Partial uniform Pressure p_0

Solver Overview



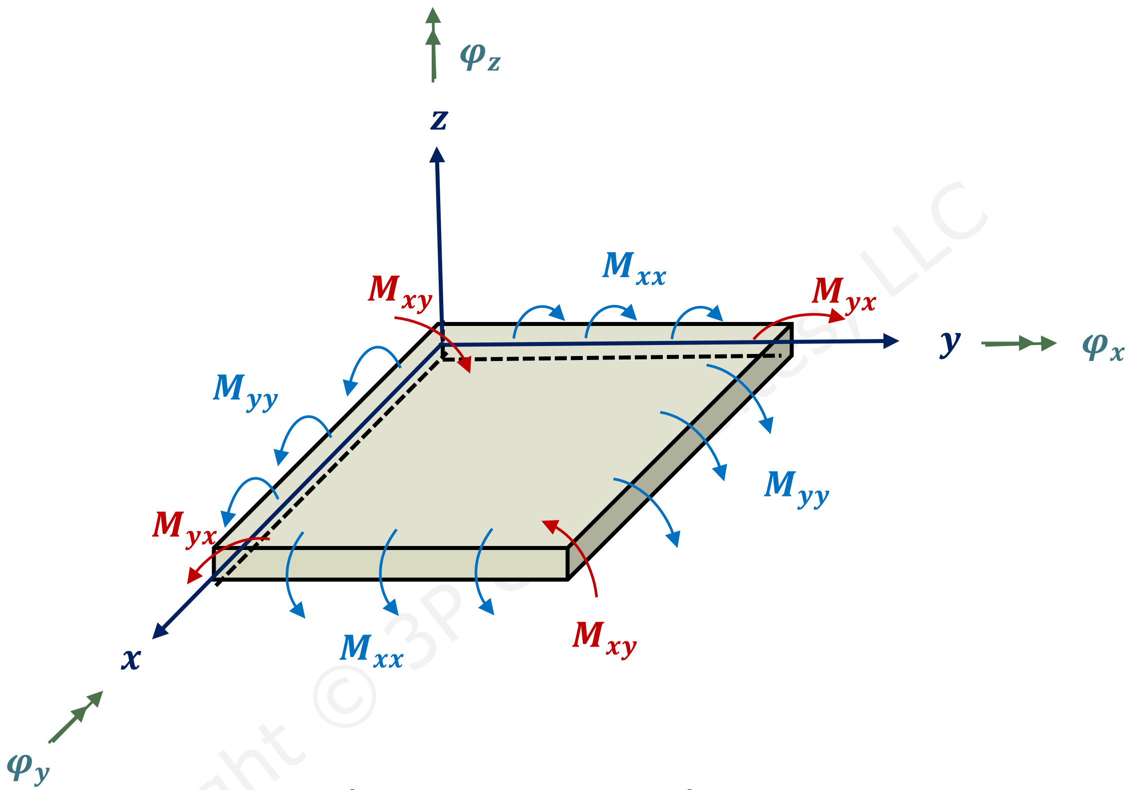


Concentrated Force P

Sinusoidal Pressure $p_0 Sin\frac{\pi x}{L} Sin\frac{\pi y}{W}$

- Positive transverse loading acts in positive $z-$direction and results in positive maximum transverse displacement w_0 . Conventionally the sandwich panels are laid-up or stacked from bottom-to-top. Hence, the positive transverse displacement w_0 would produce positive bending moments M_{xx} and M_{yy} resulting in tension in the top face sheet plies and compression in the bottom face sheet ply. Positive sign conventions of plate rotations and moments on the next Slide

Solver Overview



In-plane Moment resultants
(Moment per unit Length)

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

- **3pcsolver006** 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 transverse bending of sandwich plate (see below):

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

- In the system of equations given above, K_{ij} are the stiffness terms containing the face sheets A_{ij}, B_{ij} and D_{ij} and core transverse shear stiffnesses of the core A_{44}, A_{45} and A_{55}. u_{mn}, v_{mn} and w_{mn} are the unknown coefficients of displacements, and φ_{xmn} and $\boldsymbol{\varphi_{ymn}}$ are the unknown coefficients of rotations of the sandwich plate. P_{mn} are the known coefficients of the applied transverse loading

Theoretical Background

- Given the lamina/ply material properties, faces sheet laminate stack-up and its dimensions, **3pcsolver006** solver calculates displacements, rotations, in-plane and transverse force resultants, and moment resultants for sandwich plates subjected to any of the four types of applied transverse loading discussed earlier

- The **3pcsolver006** is based on FSDT of laminated plates, employs a closed-form Ritz solution procedure, and considers the fully anisotropic laminated face sheets. That is, 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 transverse bending analysis of sandwich plates with various types of factsheets and cores. In case of laminated composite factsheets, most closed-form analyses neglect these coupling effects due to the complexity in deriving the system of equations, and hence, assume the face sheet laminates 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 **3pcsolver006** solver, and results are compared with those (i) obtained from standard commercially available finite element analysis software, and (ii) available in open literature

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. Numerical examples highlight the adverse effects of face sheet laminate stiffness couplings on transverse bending of sandwich plates

- Details of the theoretical approach along with numerous verification and application examples are available in the training module **3pcmodule006**

Inputs

- All inputs should be in consistent units. Use either (N, m, kg, Celsius, N/mm N-m/m) OR (N, mm, Kg, Celsius, N/mm, N-mm/mm) or (lbs, in, Fahrenheit, lb/in, lb-in/in) 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 faces 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) and has no bearing on the analysis. 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	+	–

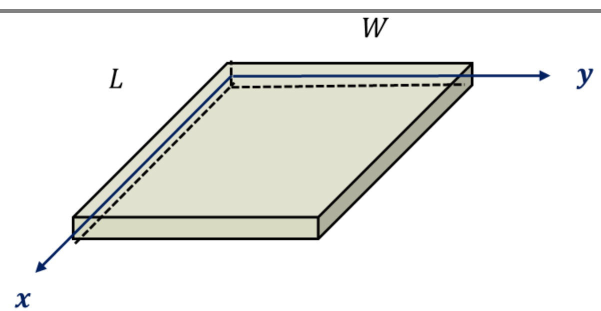
Inputs: Sandwich Panels

❖ 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:**

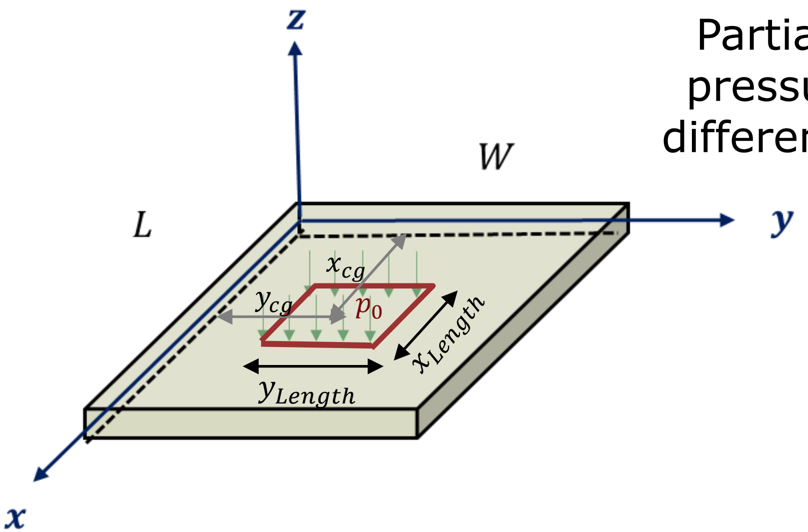
As mentioned earlier (see overview Section), four types of transverse loads can be applied to the sandwich panels. They are (i) Uniform Pressure, (ii) Partial Uniform Pressure, (iii) Point Load, and (iv) Sinusoidal Pressure.

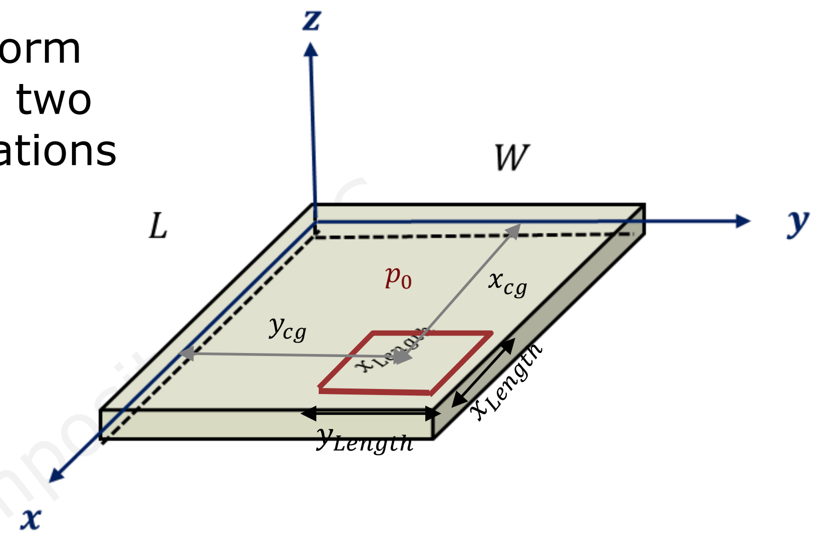
- Uniform or Sinusoidal pressure loading acts over the entire sandwich panel and can be easily defined by providing the magnitude p_0 (force per unit area) and the direction of the load. Positive value of p_0 means the pressure is acting in the positive $z-$ direction, or vice versa.

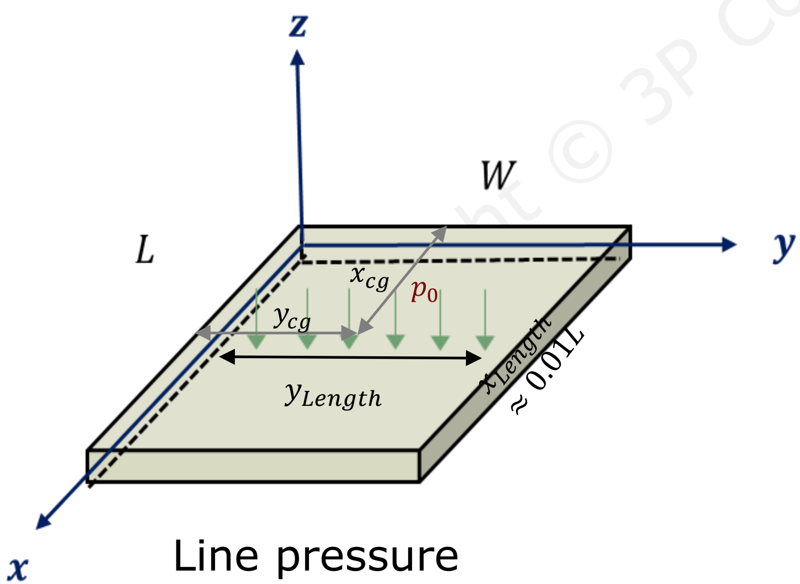
- Partial uniform pressure loading can act on a part of the panel in its domain and is defined by providing the magnitude p_0 (force per unit area),the direction of the load, the area (or patch) of the plate on which it is applied. In order to define the location and area of the partial surface over which the partial pressure loading acts, the center of the patch area defined by x_{cg} and y_{cg} and its lengths in $x-$ and $y-$directions, x_{Length} and y_{Length} respectively, are required inputs. Positive value of p_0 implies that the partial pressure is acting in the positive $z-$ direction, or vice versa. Application of partial uniform pressure loading in the solver is very versatile and can be used to define line loads and concentrated loads as well. A few examples of application of partial pressure loading are shown below:

Inputs: Partial Pressure Loads

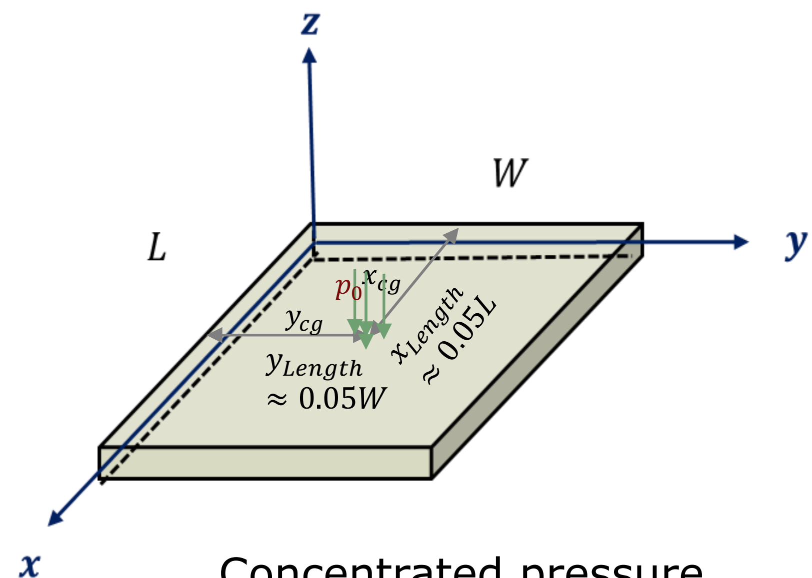
Partial uniform pressure at two different locations







Line pressure

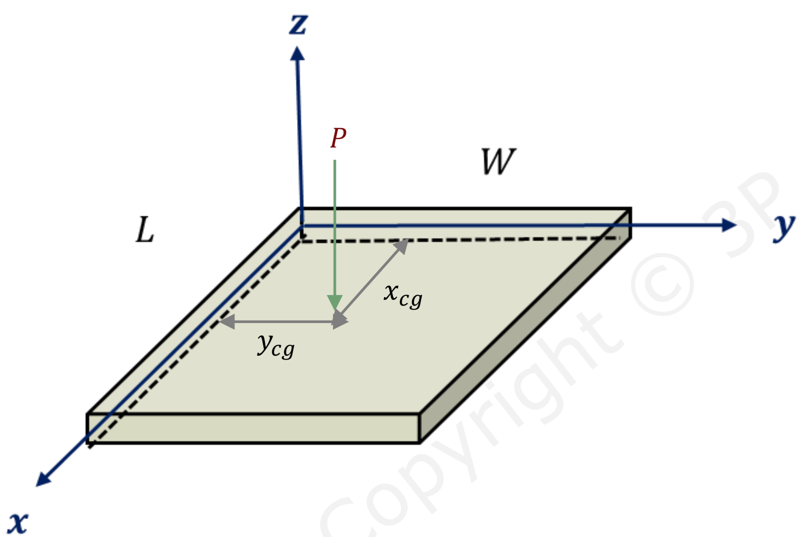


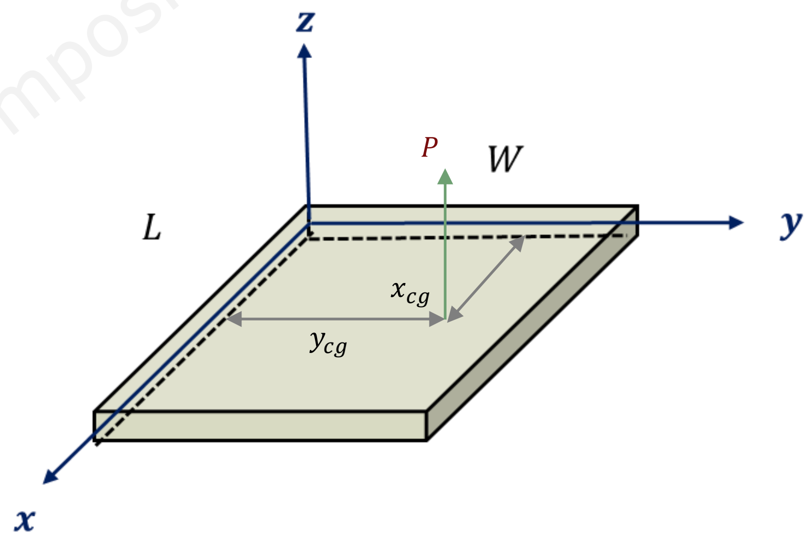
Concentrated pressure

Inputs: Point Loads

❖ **Loads:**

- Point load acts at a point on plate (or panel) in its domain and can be easily defined by providing the magnitude P (force), direction and location x_{cg} and y_{cg} of the load. Positive value of P implies that the point load is acting in the positive $z-$ direction, and vice versa. Couple of examples of application of Point loading are shown below:





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Inputs: Loads

❖ Loads:

Single or multiple sandwich panels can be easily analyzed for single or multiple load cases (upto 100 maximum). Depending upon the type of transverse loading, the examples of the load inputs for typical transverse bending analyses of sandwich plates are shown below. Additional load cases can be added by simply clicking the '+' sign on the extreme right as shown below:

Loads

ID	Panel	Type	P_0	P	x_{cg}	y_{cg}	x_{Length}	y_{Length}	
1	1	Uniform Pressure	0.05	0	0	0	0	0	+ −
2	2	Partial Pressure	0.5	0	5	5	2.0	2.0	+ −
3	4	Uniform Pressure	0.05	0	0	0	0	0	+ −
4	1	Sinusoidal Pressure	0.05	0	0	0	0	0	+ −
5	1	Point Load	0.05	5	5	5	0	0	+ −
6	1	Point Load	0.05	5	2.5	2.5	0	0	+ −
7	1	Partial Pressure	0.5	0	2.5	2.5	1.0	2.0	+ −

Inputs: Analysis Options

❖ Analysis Options:

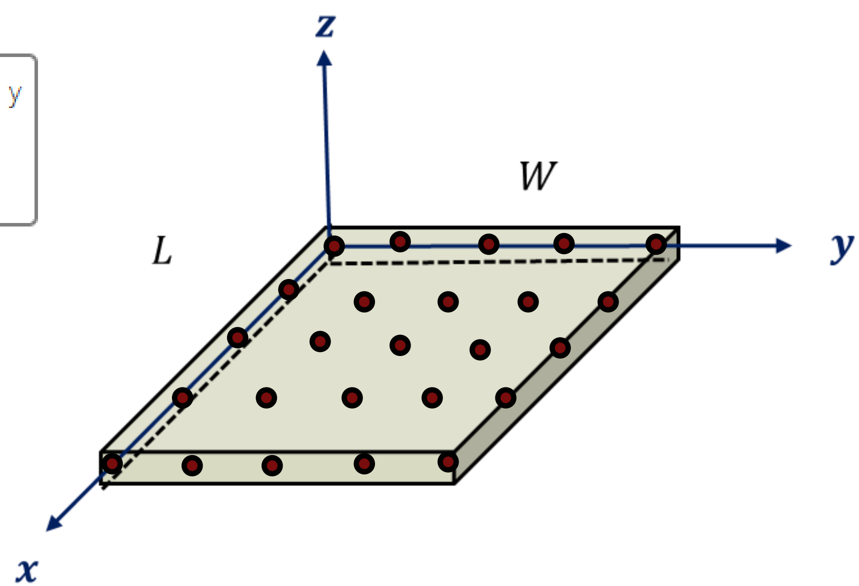
User has the option to define the number of terms in Fourier series solution of the solver. By default, $M = N = 8$ is assumed. $M = N$ can be varied from 2 to 21

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 $0 \le x \le L$ and $0 \le y \le W$ 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, 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

Output

```
3pc-solver006, v1.0b0

LOADS ID   PANEL ID
1          1

PANEL GEOMETRY
LENGTH: 15.00
WIDTH : 10.00

LOADS DESCRIPTION
TYPE: UNIFORM PRESSURE
p0: 10.00

ANALYSIS OPTIONS
m = 8
n = 8

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

Outputs

❖ Analysis Outputs:

Following information is output for each Load Case:

- Sandwich Panel Geometry and Type of Transverse Loading
- Terms in Fourier Series solution
- Number of Grid Points selected to get output information
- Material Properties and Facesheet Laminate Information
- Face sheets and Sandwich Panel [A], [B], [D] stiffness matrices
- Grid Points coordinates x and y , Displacements u, v and w, Rotations φ_x and φ_y, Sandwich Plate Force resultants N_{xx}, N_{yy}, N_{xy}, Q_{yz} and Q_{xz}, and Moment resultants M_{xx}, M_{yy} and M_{xy}

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

- Face sheet Laminate [A] stiffness matrices N/m or N/mm or lb/in
- Face sheet Laminate [B] stiffness matrices N-m/m or N-mm/mm or lb-in/in
- Face sheet Laminate [D] stiffness matrices N-m or N-mm or lb-in
- Effective Face sheet laminate in-plane and flexural - same as material property inputs
- Displacements in mm, m or in and Rotations in 1/mm, 1/m or 1/in
- Sandwich Plate Force resultants in N/m, N/mm or lb/in and Moment resultants in N-m/m, N-mm/mm or lb-in/in

A typical output is shown below:

Output Text

```
3pc-solver006, v1.0b0

LOADS ID  PANEL ID
1         1

PANEL GEOMETRY
LENGTH: 15.00
WIDTH : 10.00

LOADS DESCRIPTION
TYPE: UNIFORM PRESSURE
p0: 20.00

ANALYSIS OPTIONS
m = 8
n = 8

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

                    MATERIAL PROPERTIES
 MATERIAL PROPERTIES                  ID       E1        E2        G12        G23        G13
v12
1   1.68e+07     1.16e+06     8.00e+05     0.00e+00     0.00e+00     0.3500
2    2          1.00e+03     1.00e+03     1.00e+01     6.00e+03     1.30e+04     0.1000

BOTTOM FACESHEET LAMINATE GEOMETRY
STACKING SEQUENCE (PLY ANG): [+0.0       , +90.0      , +45.0      , -45.0      , +0.0       , +90.0
]STACKING SEQUENCE (PLY MAT): [1          , 1          , 1          , 1          , 1          , 1          ]
TOTAL THICKNESS: 0.0315

    CORE GEOMETRY
CORE ANG: +0.0
CORE MAT: Ncore
THICKNESS: 0.5000
```

Output Text

TOP FACESHEET LAMINATE GEOMETRY
STACKING SEQUENCE (PLY ANG): [+90.0 , +0.0 , -45.0 , +45.0 , +90.0 , +0.0]
STACKING SEQUENCE (PLY MAT): [1 , 1 , 1 , 1 , 1 , 1]
TOTAL THICKNESS: 0.0315

BOTTOM FACESHEET LAMINATE PROPERTIES

A MATRIX

+248285.53	+49895.58	+0.00
+49895.58	+248285.53	+0.00
+0.00	+0.00	+62197.49

B MATRIX

-434.75	+0.00	-108.69
+0.00	+434.75	-108.69
-108.69	-108.69	+0.00

D MATRIX

+23.25	+1.41	-0.00
+1.41	+23.25	+0.00
-0.00	+0.00	+2.42

TOP FACESHEET LAMINATE PROPERTIES

A MATRIX

+248285.53	+49895.58	+0.00
+49895.58	+248285.53	+0.00
+0.00	+0.00	+62197.49

B MATRIX

+434.75	+0.00	+108.69
+0.00	-434.75	+108.69
+108.69	+108.69	+0.00

D MATRIX

+23.25	+1.41	+0.00
+1.41	+23.25	+0.00
+0.00	+0.00	+2.42

Output Text

SANDWICH PLATE PROPERTIES

TOTAL THICKNESS: 0.5630

A MATRIX

+497076.11	+99841.67	+0.00
+99841.67	+497076.11	+0.00
+0.00	+0.00	+124399.97

A MATRIX - TRANSVERSE SHEAR

+3000.00	+0.00
+0.00	+6500.00

B MATRIX

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

D MATRIX

+35588.53	+7051.42	+115.54
+7051.42	+34664.25	+115.54
+115.54	+115.54	+8790.11

EFFECTIVE BOTTOM FACESHEET LAMINATE INPLANE AND FLEXURAL ENGINEERING CONSTANTS

Ex Ey Gxy vxy vyx Efx Efy Gfxy vfxy vfyx
+7.53e+06 +7.53e+06 +1.92e+06 +0.2058 +0.2058 +8.89e+06 +8.89e+06 +8.53e+05 +0.0616
+0.0616

EFFECTIVE TOP FACESHEET LAMINATE INPLANE AND FLEXURAL ENGINEERING CONSTANTS

Ex Ey Gxy vxy vyx Efx Efy Gfxy vfxy vfyx
+7.53e+06 +7.53e+06 +1.92e+06 +0.2058 +0.2058 +8.89e+06 +8.89e+06 +8.53e+05 +0.0616
+0.0616

Output Text

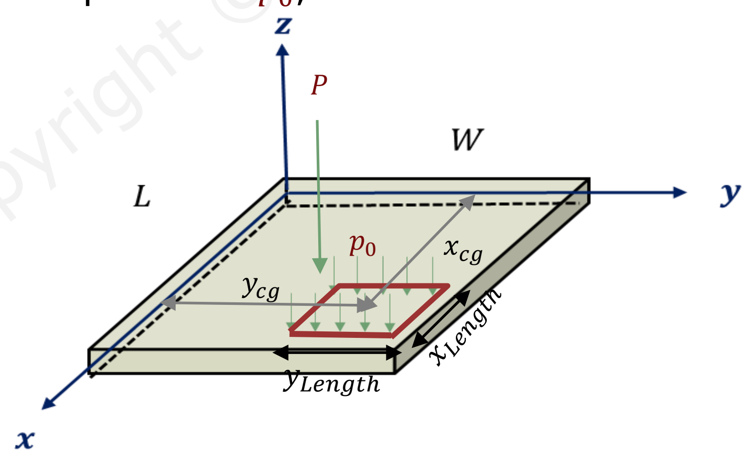
GRID POINTS, DISPLACEMENTS, ROTATIONS, FORCES, AND MOMENTS

X	Y	U	V	W	PHIX	PHIY	NXX	NYY	NXY	MXX	MYY	MXY	QYZ	QXZ
0.0000	0.0000	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	-0.0000	+0.0000	-0.0000	-0.0000	+0.0000	-37.6856	+0.0000	+0.0000
3.7500	0.0000	+0.0000e+00	-1.1651e-18	+0.0000e+00	+0.0000e+00	-7.3531e-03	-0.0000	+0.0000	-0.0000	-0.0000	+0.0000	-22.2473	+32.3649	+0.0000
7.5000	0.0000	+0.0000e+00	-1.6846e-18	+0.0000e+00	+0.0000e+00	-1.0048e-02	-0.0000	+0.0000	-0.0000	-0.0000	+0.0000	-0.0000	+39.7437	+0.0000
11.2500	0.0000	+0.0000e+00	-1.1651e-18	+0.0000e+00	+0.0000e+00	-7.3531e-03	+0.0000	-0.0000	+0.0000	+0.0000	-0.0000	+22.2473	+32.3649	+0.0000
15.0000	0.0000	+0.0000e+00	-9.2888e-34	+0.0000e+00	+0.0000e+00	-5.8764e-18	+0.0000	-0.0000	+0.0000	+0.0000	-0.0000	+37.6856	+0.0000	+0.0000
0.0000	2.5000	-7.8691e-19	+0.0000e+00	+0.0000e+00	-8.1807e-03	+0.0000e+00	-0.0000	+0.0000	-0.0000	-0.0000	+0.0000	-23.0728	+0.0000	+27.7313
3.7500	2.5000	-3.9390e-19	-7.7106e-19	+3.6303e-02	-4.9310e-03	-4.9221e-03	-0.0000	-0.0000	-0.0000	+39.9792	+47.8605	-14.9190	+14.7174	+8.2224
7.5000	2.5000	-1.7659e-34	-1.1284e-18	+4.7699e-02	-2.0594e-18	-6.7866e-03	-0.0000	-0.0000	-0.0000	+44.1755	+63.2230	-0.0000	+19.5386	+0.0000
11.2500	2.5000	+3.9390e-19	-7.7106e-19	+3.6303e-02	+4.9310e-03	-4.9221e-03	-0.0000	-0.0000	+0.0000	+39.9792	+47.8605	+14.9190	+14.7174	-8.2224
15.0000	2.5000	+7.8691e-19	-6.1699e-34	+2.9331e-17	+8.1807e-03	-3.9300e-18	-0.0000	-0.0000	+0.0000	+0.0000	+0.0000	+23.0728	+0.0000	-27.7313
0.0000	5.0000	-1.0856e-18	+0.0000e+00	+0.0000e+00	-1.1090e-02	+0.0000e+00	-0.0000	+0.0000	-0.0000	-0.0000	+0.0000	-0.0000	+0.0000	+33.7408
3.7500	5.0000	-5.6840e-19	-8.4654e-35	+4.8688e-02	-6.8364e-03	-4.6680e-19	-0.0000	-0.0000	-0.0000	+53.5961	+61.2554	-0.0000	+0.0000	+11.3631
7.5000	5.0000	-2.4709e-34	-9.4132e-35	+6.4578e-02	-2.8363e-18	-5.6965e-19	-0.0000	-0.0000	-0.0000	+60.6033	+82.0635	-0.0000	+0.0000	+0.0000
11.2500	5.0000	+5.6840e-19	-4.3243e-35	+4.8688e-02	+6.8364e-03	-3.5547e-19	-0.0000	-0.0000	-0.0000	+53.5961	+61.2554	+0.0000	+0.0000	-11.3631
15.0000	5.0000	+1.0856e-18	-3.8289e-50	+3.9211e-17	+1.1090e-02	-3.3213e-34	-0.0000	-0.0000	+0.0000	+0.0000	+0.0000	+0.0000	+0.0000	-33.7408
0.0000	7.5000	-7.8691e-19	+0.0000e+00	+0.0000e+00	-8.1807e-03	+0.0000e+00	+0.0000	-0.0000	+0.0000	+0.0000	-0.0000	+23.0728	+0.0000	+27.7313
3.7500	7.5000	-3.9390e-19	+7.7106e-19	+3.6303e-02	-4.9310e-03	+4.9221e-03	-0.0000	-0.0000	+0.0000	+39.9792	+47.8605	+14.9190	-14.7174	+8.2224
7.5000	7.5000	-1.7156e-34	+1.1284e-18	+4.7699e-02	-2.0610e-18	+6.7866e-03	-0.0000	-0.0000	+0.0000	+44.1755	+63.2230	+0.0000	-19.5386	+0.0000
11.2500	7.5000	+3.9390e-19	+7.7106e-19	+3.6303e-02	+4.9310e-03	+4.9221e-03	-0.0000	-0.0000	-0.0000	+39.9792	+47.8605	-14.9190	-14.7174	-8.2224
15.0000	7.5000	+7.8691e-19	+6.1699e-34	+2.9331e-17	+8.1807e-03	+3.9300e-18	-0.0000	-0.0000	-0.0000	+0.0000	+0.0000	-23.0728	-0.0000	-27.7313
0.0000	10.0000	-1.4264e-34	+0.0000e+00	+0.0000e+00	-1.5296e-18	+0.0000e+00	+0.0000	-0.0000	+0.0000	+0.0000	-0.0000	+37.6856	+0.0000	+0.0000
3.7500	10.0000	-6.5877e-35	+1.1651e-18	+7.0718e-18	-8.7470e-19	+7.3531e-03	+0.0000	-0.0000	+0.0000	+0.0000	+0.0000	+22.2473	-32.3649	+0.0000
7.5000	10.0000	-1.5051e-50	+1.6846e-18	+9.0811e-18	-3.2665e-34	+1.0048e-02	-0.0000	-0.0000	+0.0000	+0.0000	+0.0000	+0.0000	-39.7437	+0.0000
11.2500	10.0000	+6.5877e-35	+1.1651e-18	+7.0718e-18	+8.7470e-19	+7.3531e-03	-0.0000	+0.0000	-0.0000	+0.0000	+0.0000	-22.2473	-32.3649	-0.0000
15.0000	10.0000	+1.4264e-34	+9.2888e-34	+5.8244e-33	+1.5296e-18	+5.8764e-18	-0.0000	+0.0000	-0.0000	-0.0000	+0.0000	-37.6856	-0.0000	-0.0000

Output: Additional Postprocessing

❖ Postprocessing:

- User can download the output information as ASCII text and process the information using MS Excel/ MATLAB etc. to create plots of displacements, rotations and moments etc. along $x-$ and $y-$ axes of the plate.
- Plate Force resultants N_{xx}, N_{yy}, N_{xy}, Q_{yz} and Q_{xz}, and Plate Moment resultants M_{xx}, M_{yy} and M_{xy} at a select grid points or $x-$ and $y-$coordinates of the plate can be used as inputs to the 3pcsolver005 solver to further obtain the following:
    - Facesheet laminate strains and curvatures
    - Facesheet laminate ply-by-ply strains and stresses
    - Facesheet laminate/lamina Failure Indices or Margins of Safety
    - Sandwich failure modes analysis
- Since 3pcsolver006 solver performs linear analysis, principle of superposition can be utilized to perform bending analyses of sandwich panels subjected to various combinations of the four types of transverse loads. One such combination, Point load P and partial pressure p_0, is shown below:



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}	$mm/mm/$°C	$m/m/$°C	$in/in/$°F
β_1, β_2 , β_x , β_y, β_{xy}	$mm/mm/Kg/Kg$	$m/m/Kg/Kg$	$in/in/lb/lb$
$\sigma_{11}^T, \sigma_{11}^C, \sigma_{22}^T, \sigma_{22}^C\ \tau_{12}^S, \sigma_1, \sigma_2, \tau_{12}, \tau_{23}, \tau_{13},$ $\sigma_x, \sigma_y, \tau_{xy}, \tau_{yz}, \tau_{xz}, p_0$	$MPa\ (N/mm^2)$	$Pa\ (N/m^2)$	$Psi\ (lb/in^2)$
$\varepsilon_{11}^T, \varepsilon_{11}^C, \varepsilon_{22}^T, \varepsilon_{22}^C, \gamma_{12}, \varepsilon_1, \varepsilon_2, \gamma_{12}, \gamma_{13}, \gamma_{23}, \varepsilon_{x0},$ $\varepsilon_{y0}, \gamma_{xy0}, \gamma_{yz0}, \gamma_{xz0}\ \varepsilon_x, \varepsilon_y, \gamma_{xy}, \gamma_{yz}, \gamma_{xz}$	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
$M_{xx}, M_{yy}, M_{xy}, M_{xx}^T, M_{yy}^T, M_{xy}^T,$ $M_{xx}^H, M_{yy}^H, M_{xy}^H$, [B], P	$N-mm/mm$	$N-m/m$	$lb-in/in$
[D]	$N-mm$	$N-m$	$lb-in$
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, 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:

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 3pcsolver006 is $39/year per for a single-login license

- Training module 3pcmodule006 supports the solver 3pcsolver006. 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 3pcsolver006 and 3pcmodule006. 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

Examples: Bending 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 $\frac{L}{W} = 1.5$

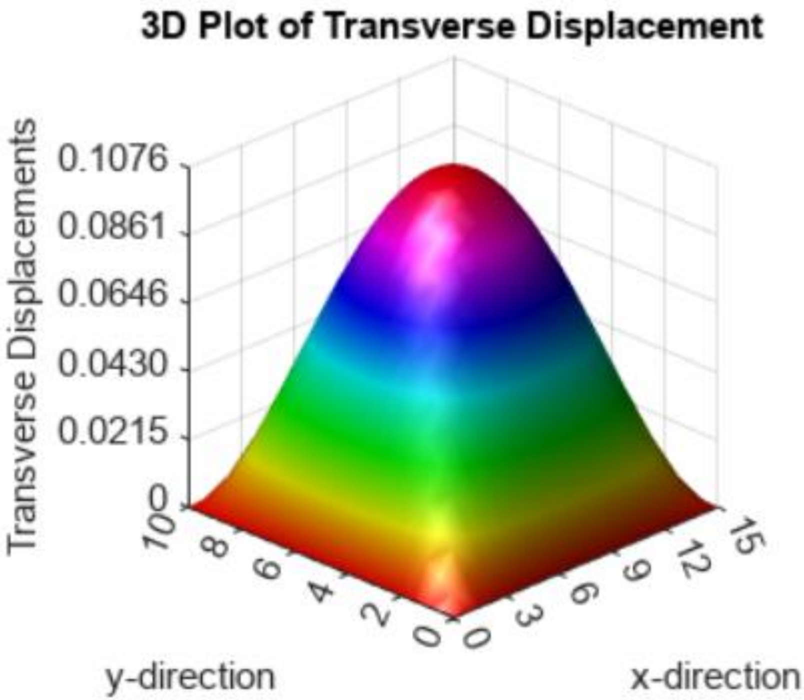
- Bottom Facesheet Laminate: $[0/90/\pm45/0/90]_T$

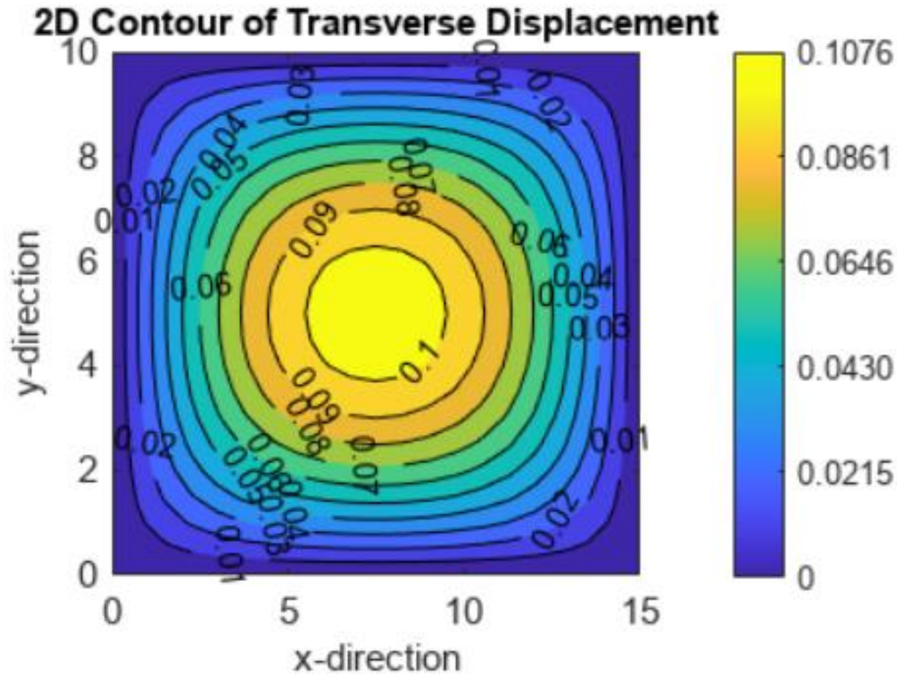
- Top Facesheet Laminate: $[90/0/\mp45/90/0]_T$

- Load Cases:
  - I: Uniform Pressure Load p_0 = 20 Psi
  - II: Sinusoidal Pressure Load p_0 = 20 Psi
  - III: Concentrated Load P = 1000 lb
  - IV: Partial Pressure Load p_0 = 1000 Psi over $1\ in^2$

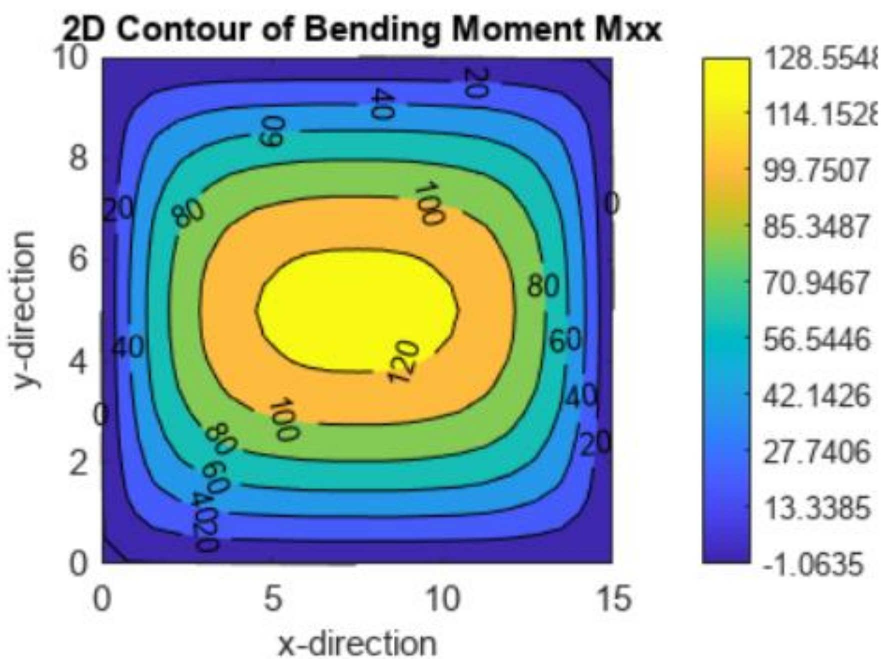
- MATLAB scripts are used to plot transverse displacement w, moment resultants M_{xx}, M_{yy} and M_{xy} and the transverse shear force resultants Q_{xz} and Q_{yz} in the laminated plate subjected to transverse loading

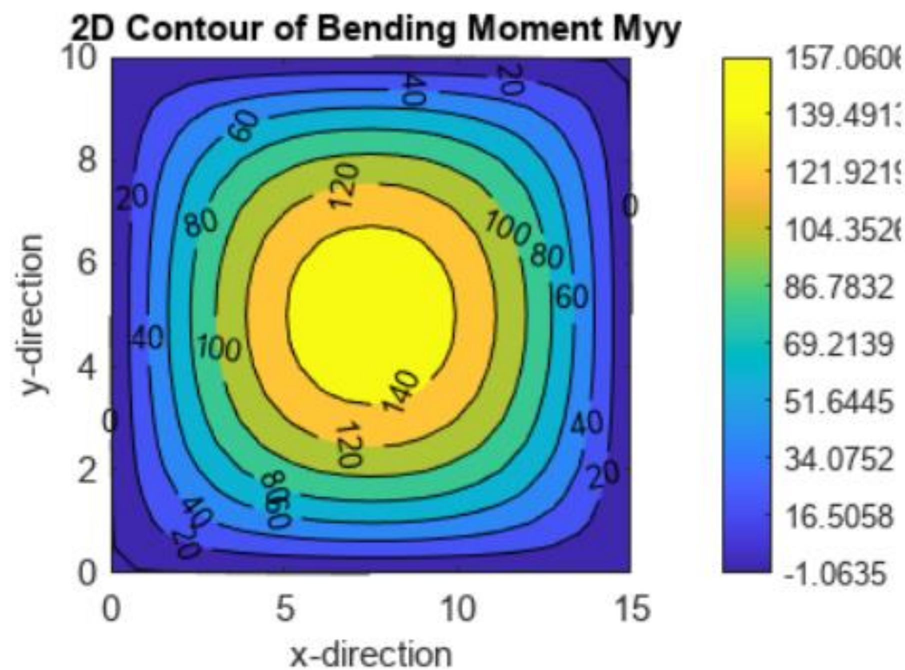
Sandwich Plate Bending under Uniform Pressure



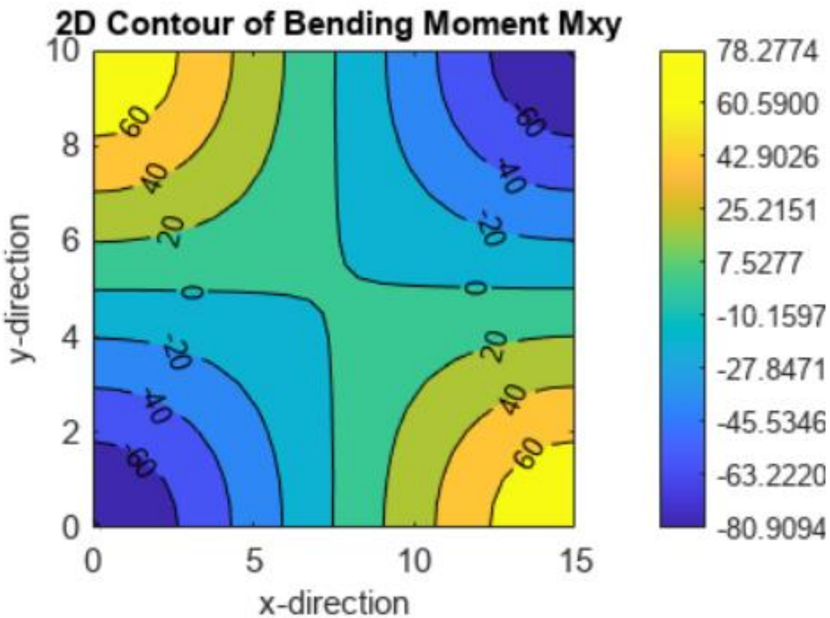


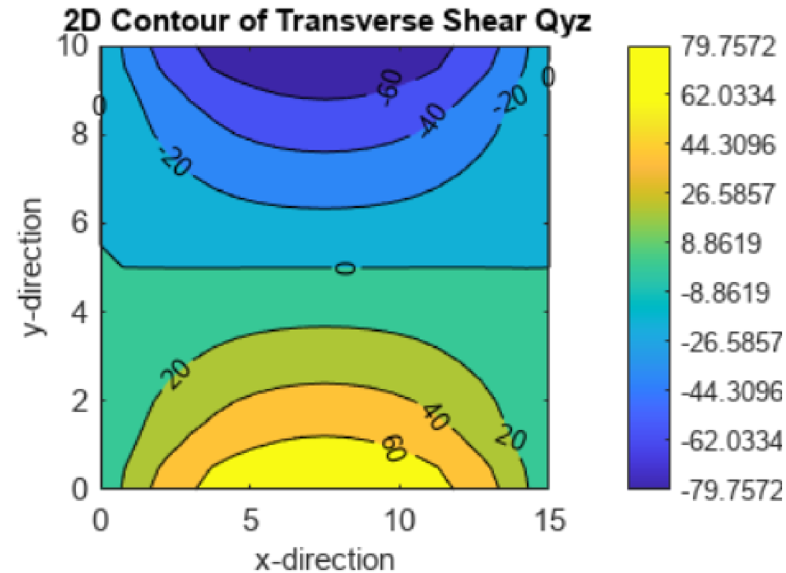
Sandwich Plate Bending under Uniform Pressure

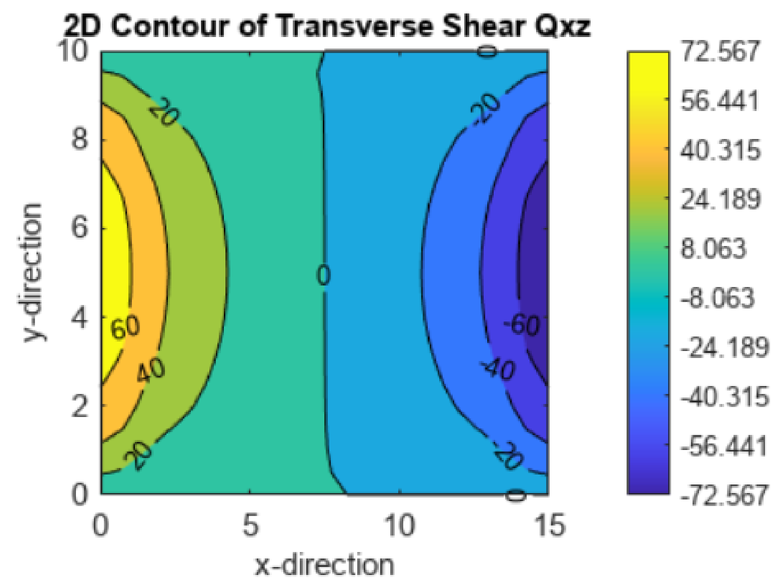




Sandwich Plate Bending under Uniform Pressure

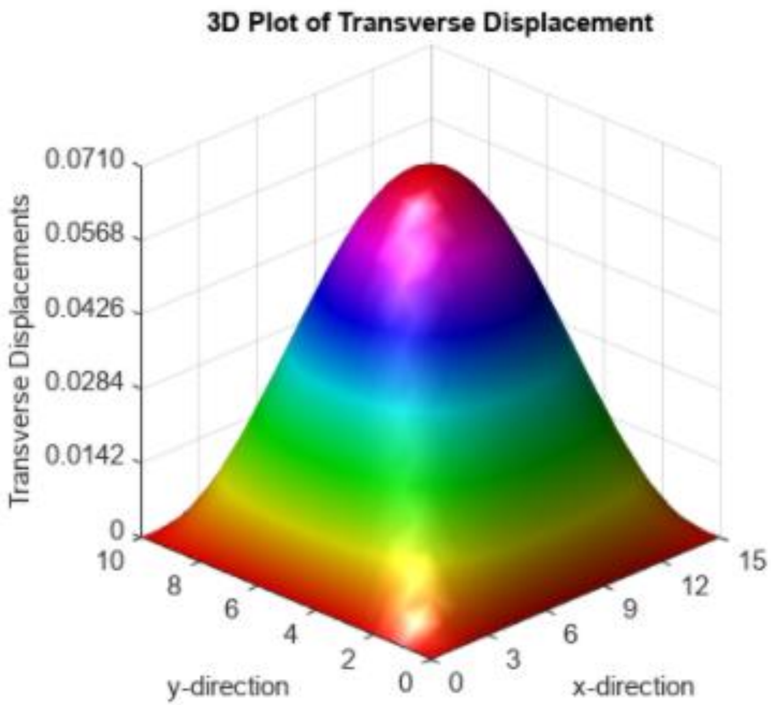


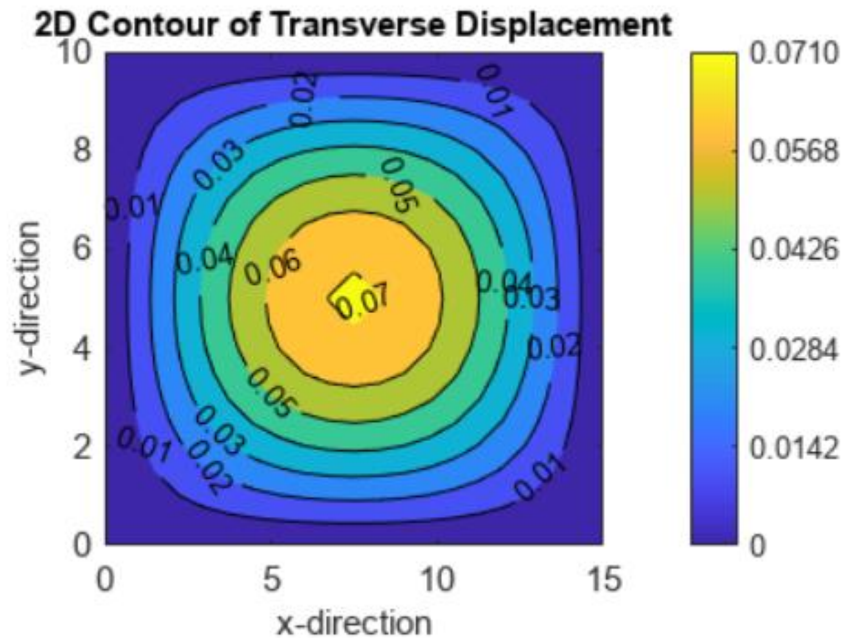




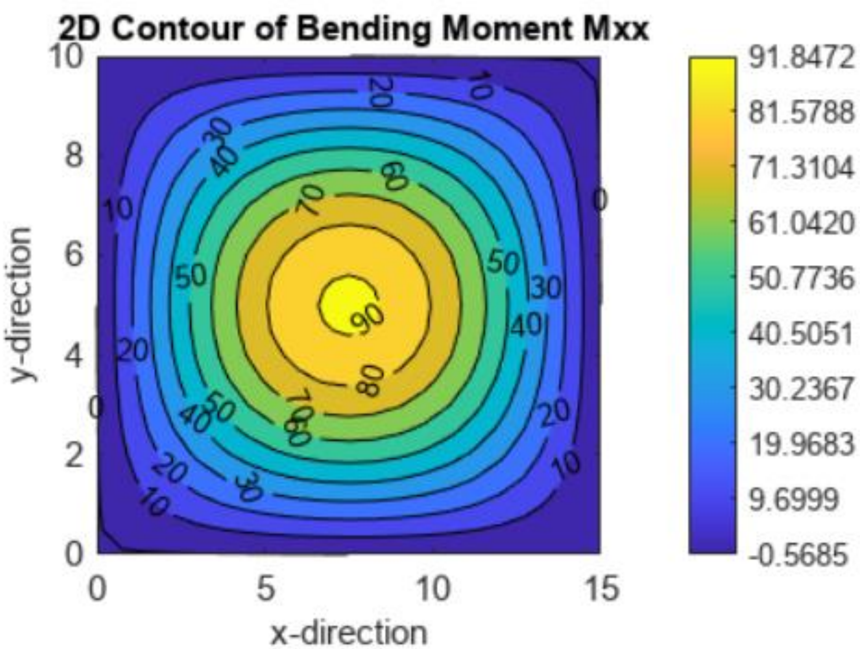
3P COMPOSITES

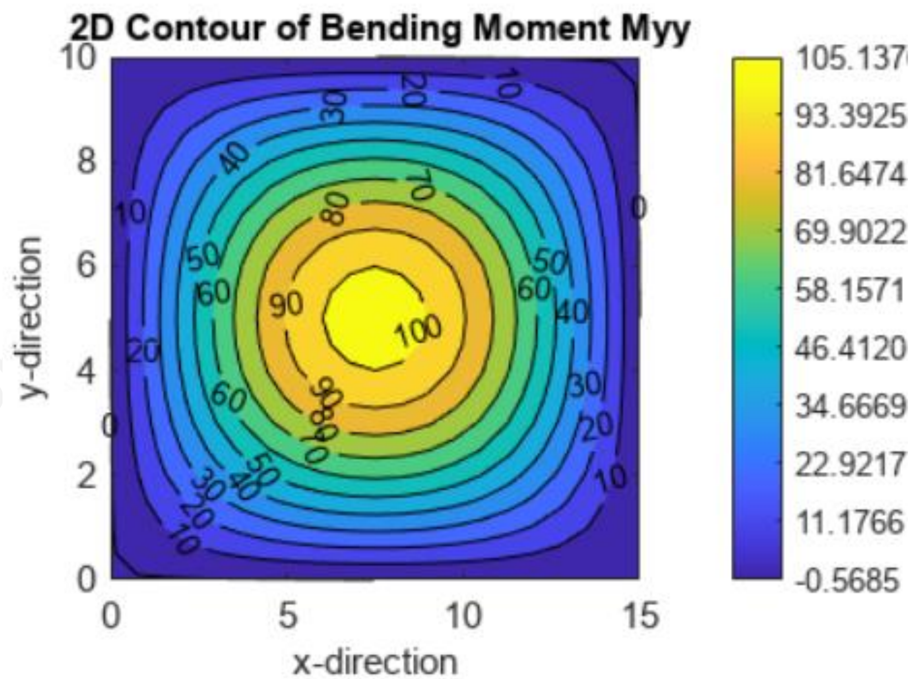
Sandwich Plate Bending under Sine Pressure



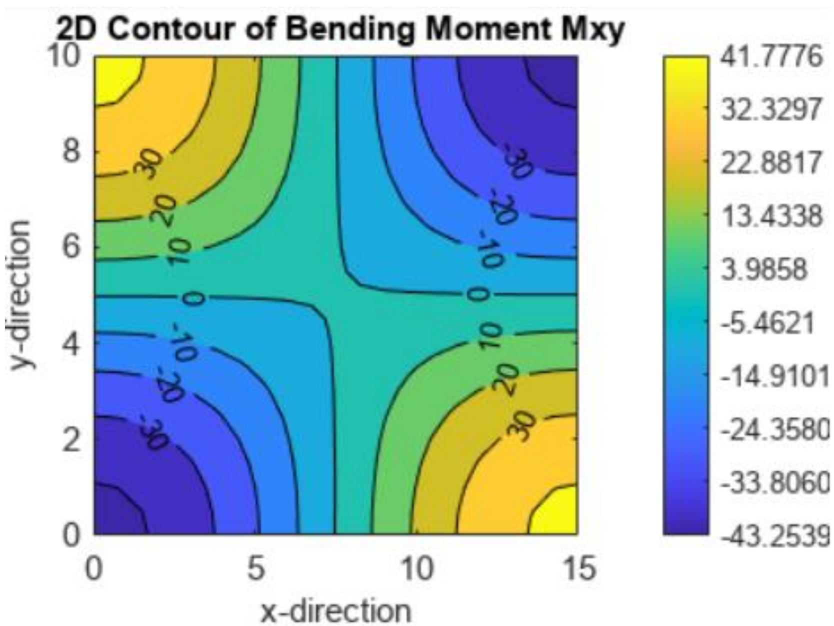


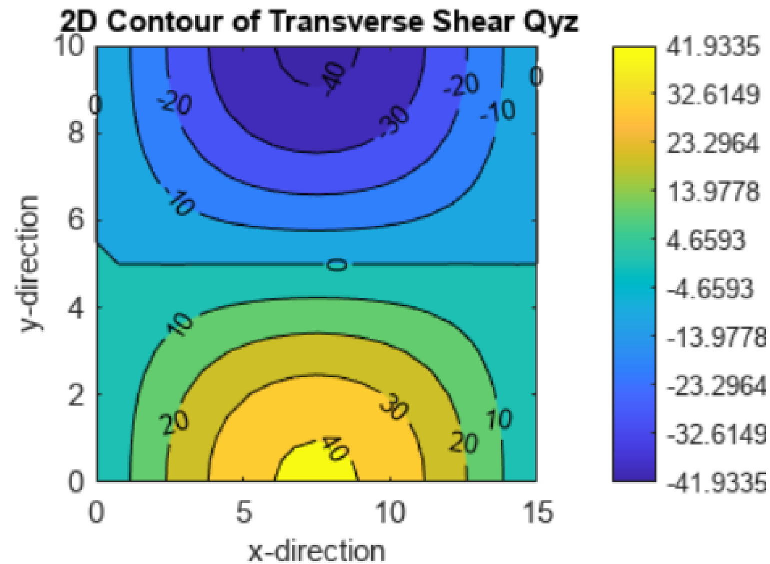
Sandwich Plate Bending under Sine Pressure

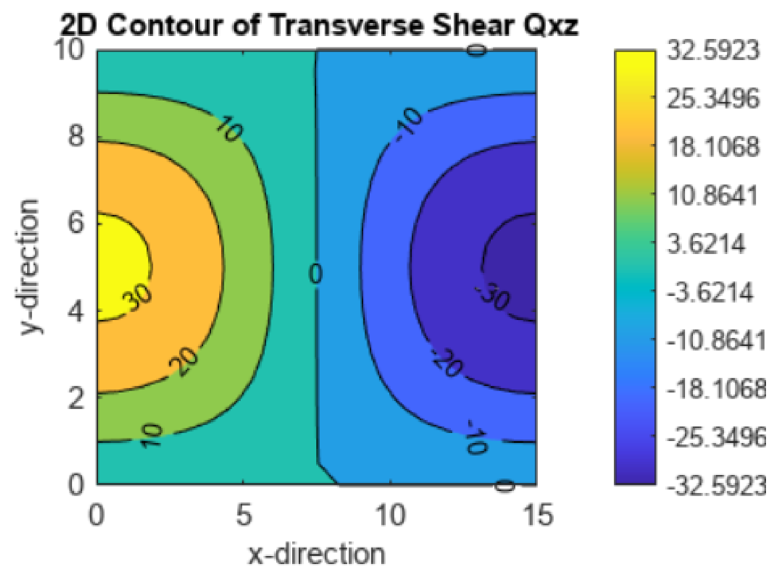




Sandwich Plate Bending under Sine Pressure

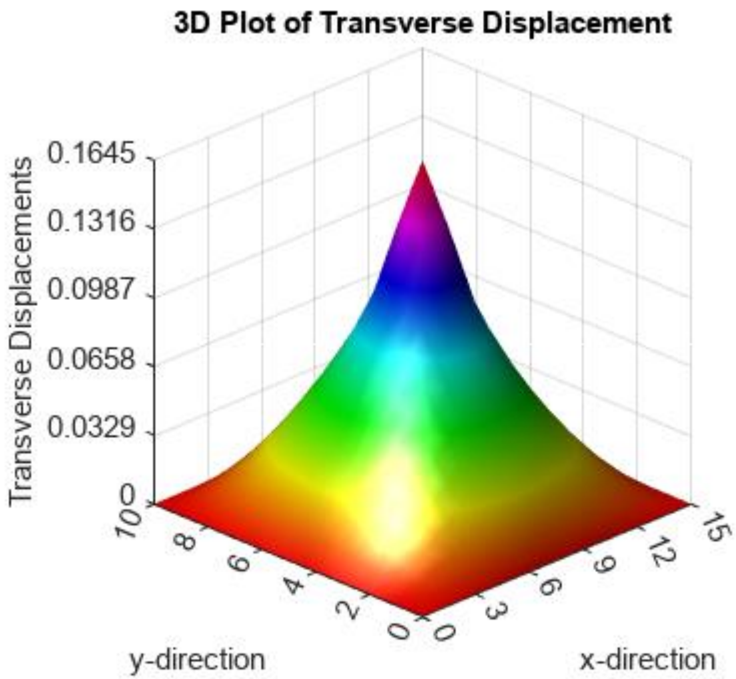


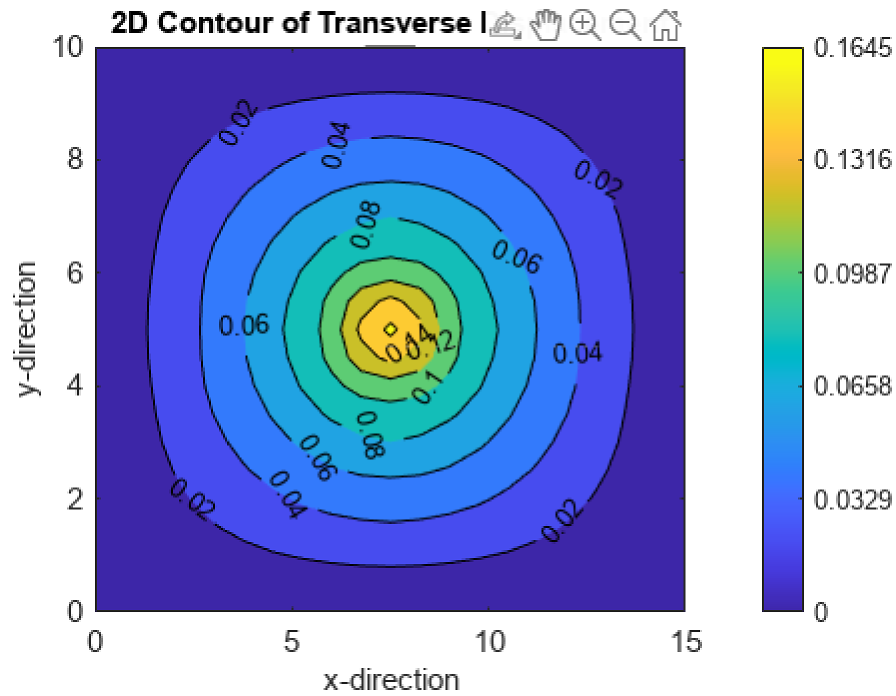




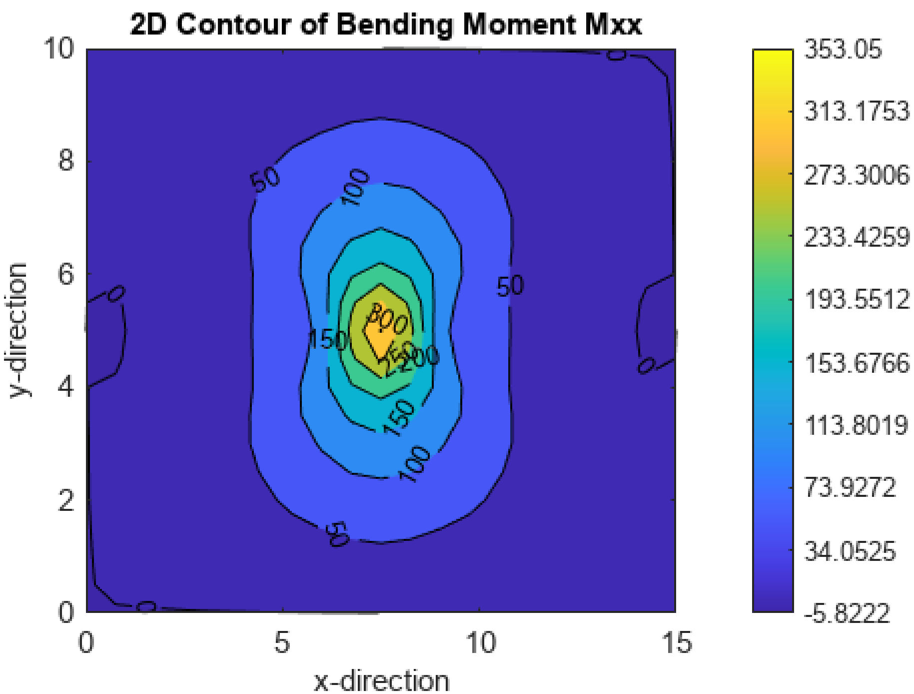
3P COMPOSITES

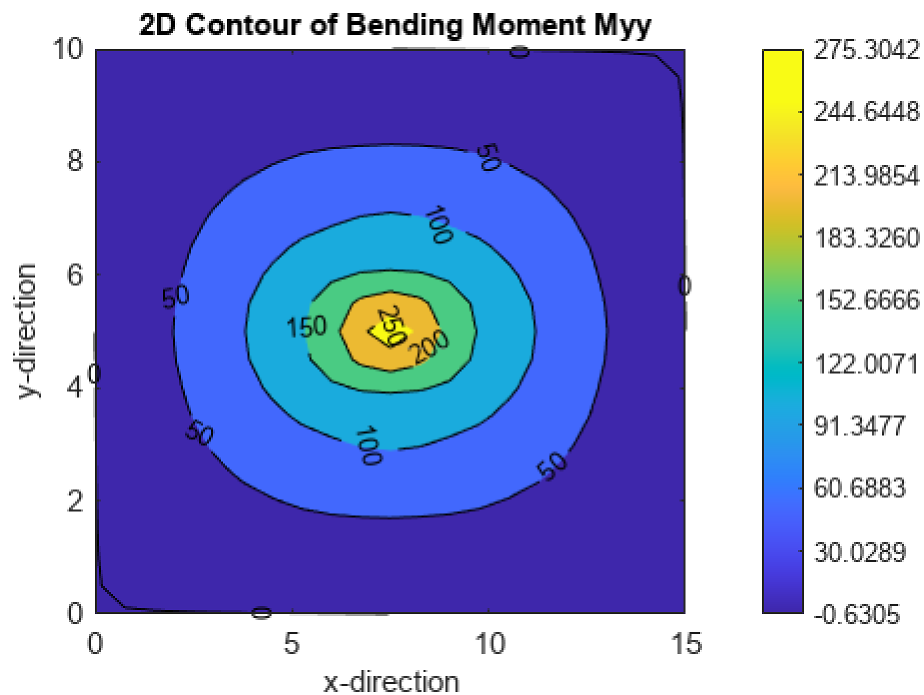
Sandwich Plate Bending under Point Load





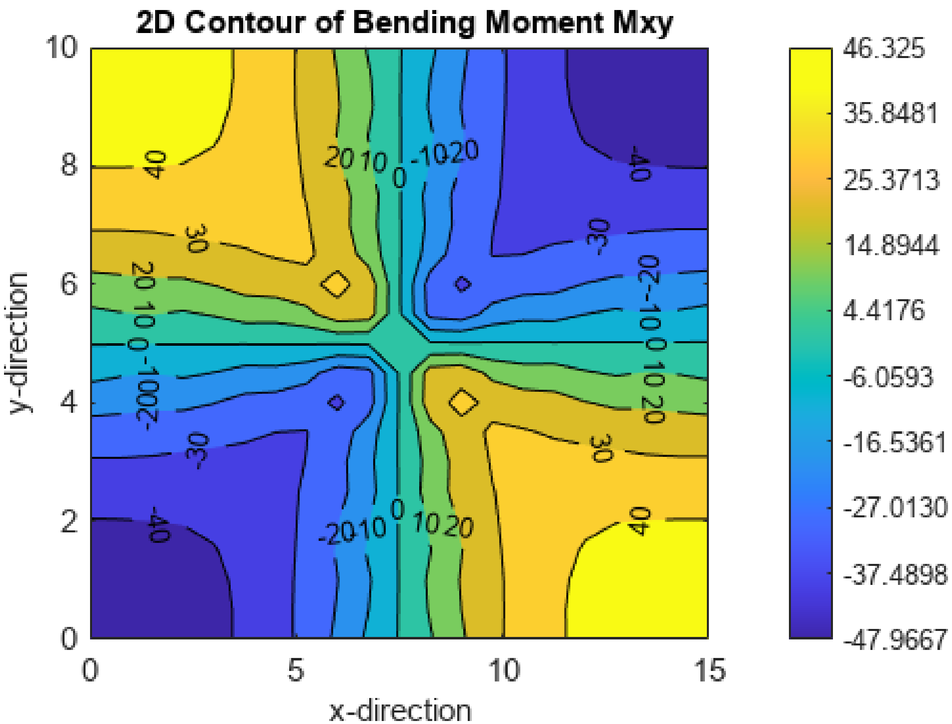
Sandwich Plate Bending under Point Load

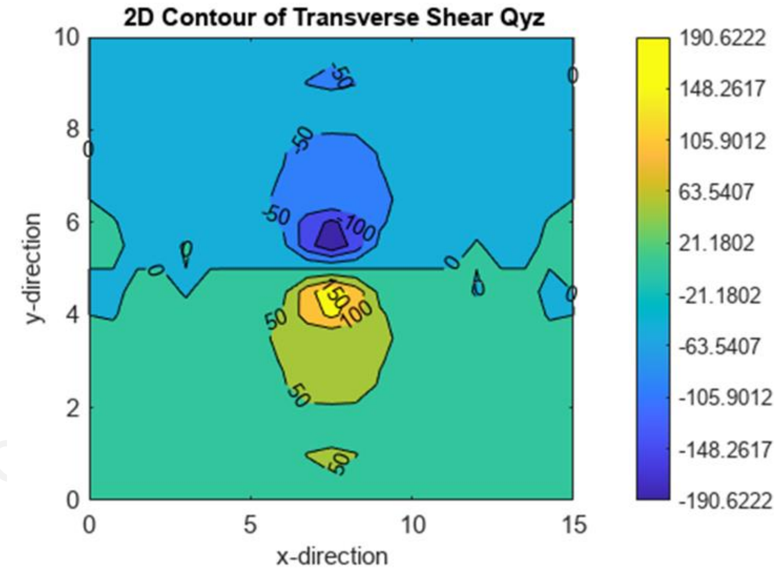


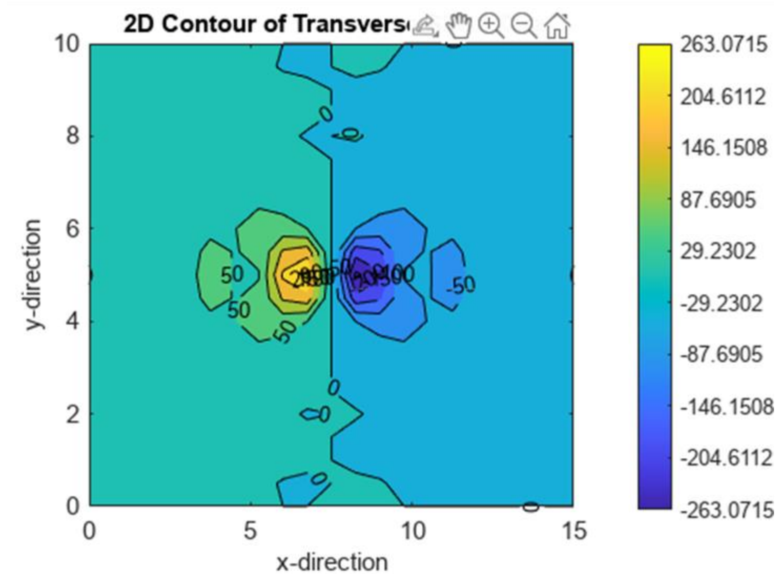


3P COMPOSITES
PRODUCIBILITY
PERFORMANCE
PROFITABILITY

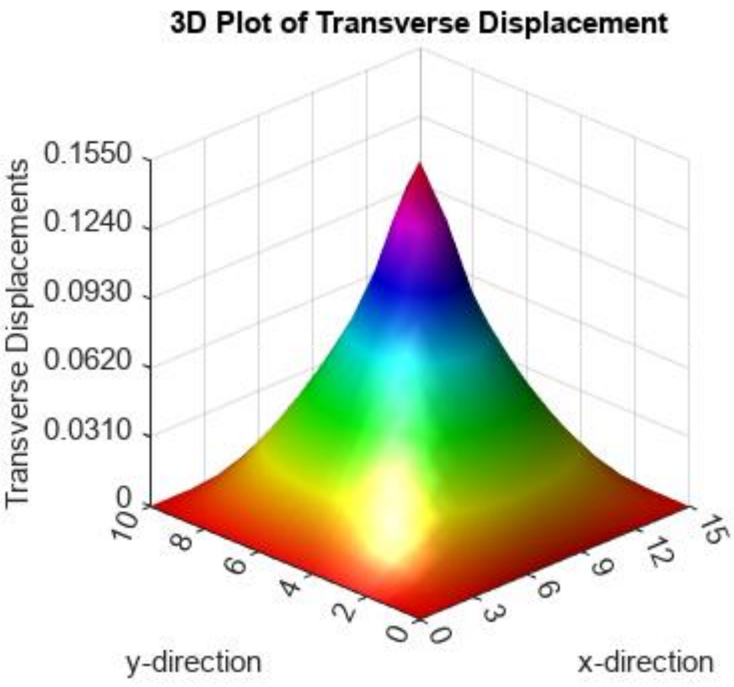
Sandwich Plate Bending under Point Load

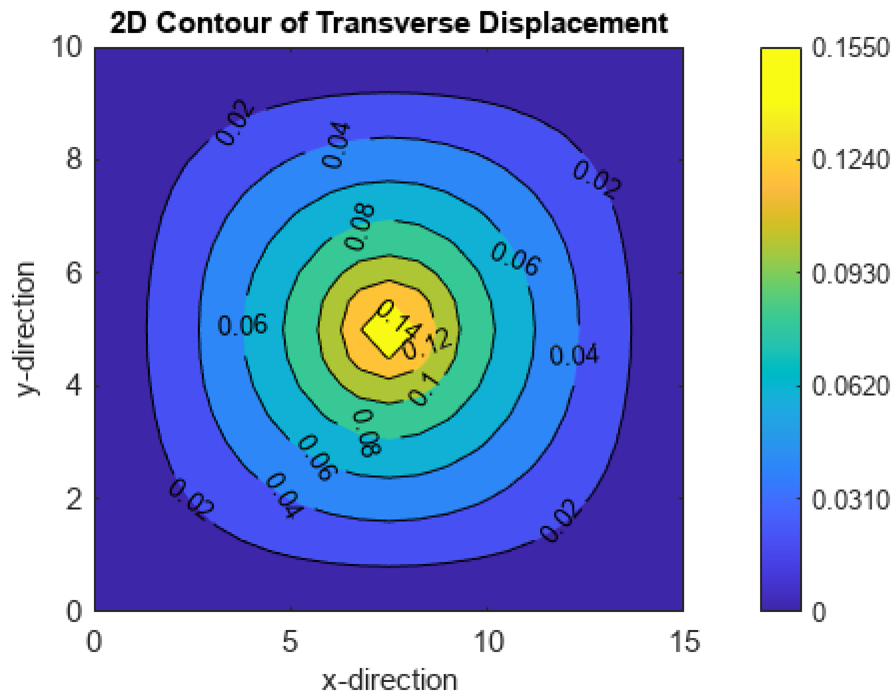




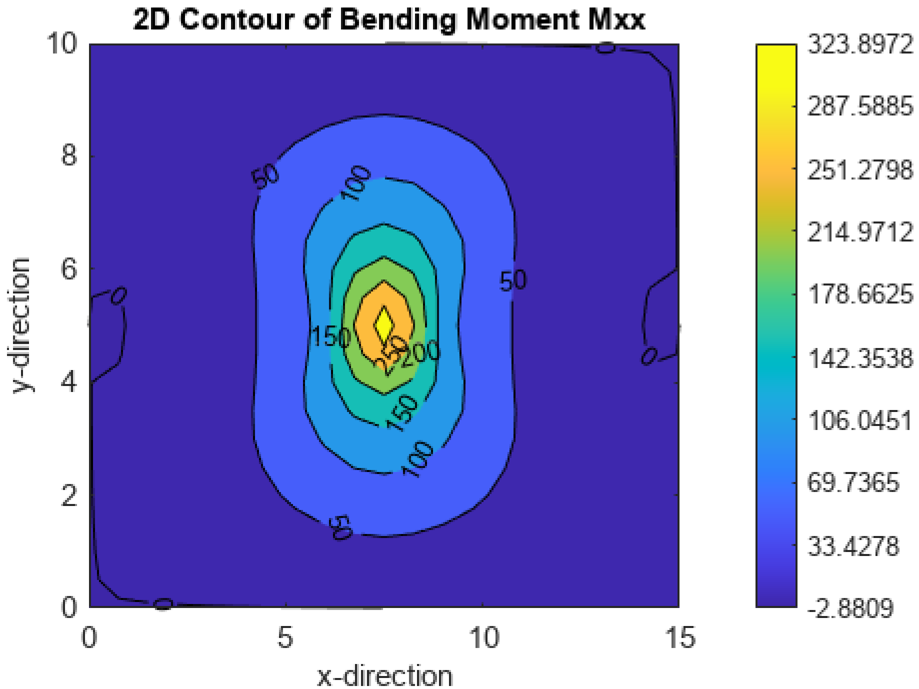


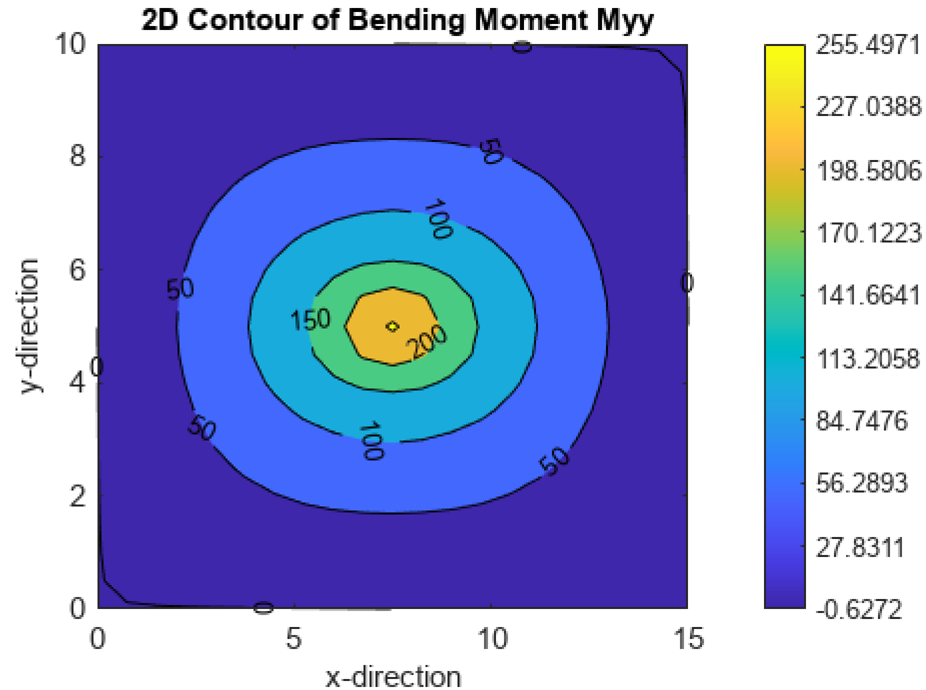
Sandwich Plate under Partial Pressure



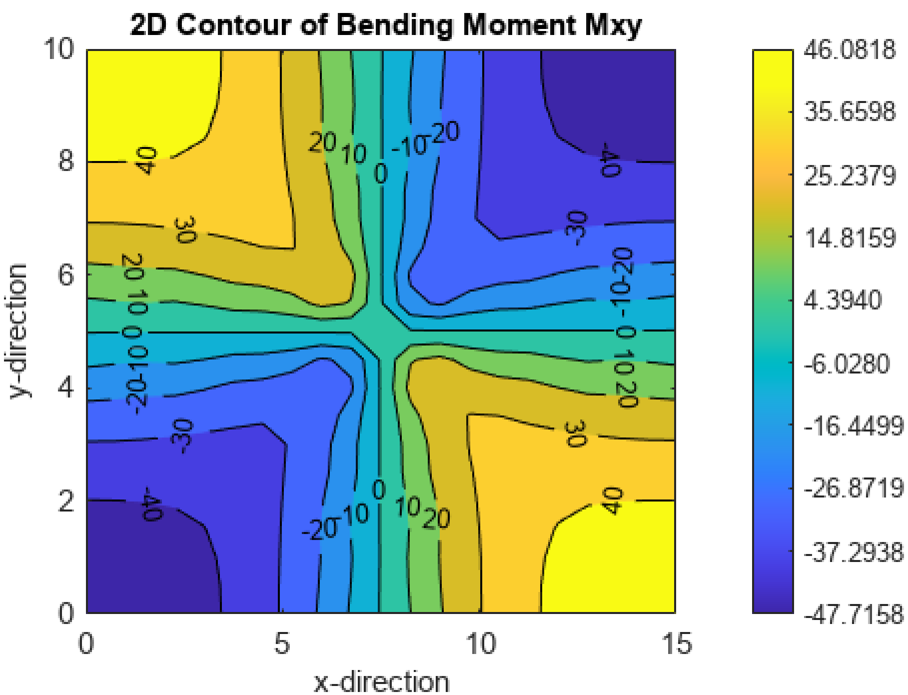


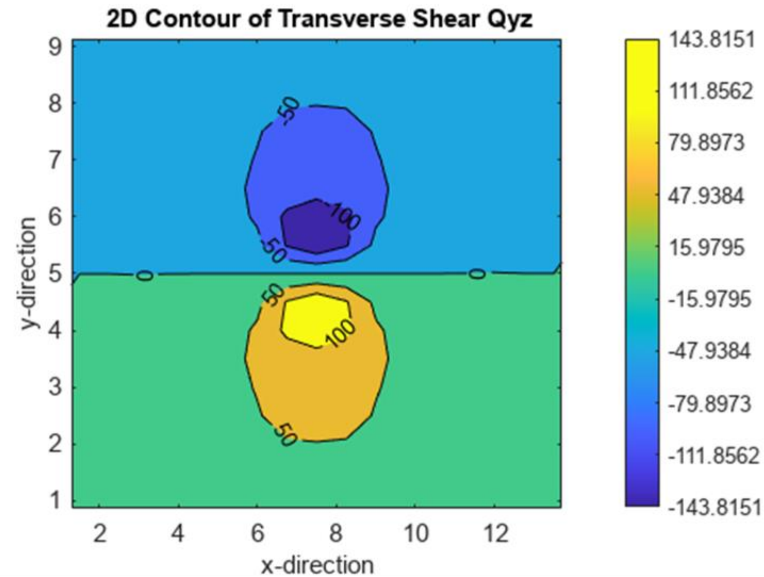
Sandwich Plate under Partial Pressure

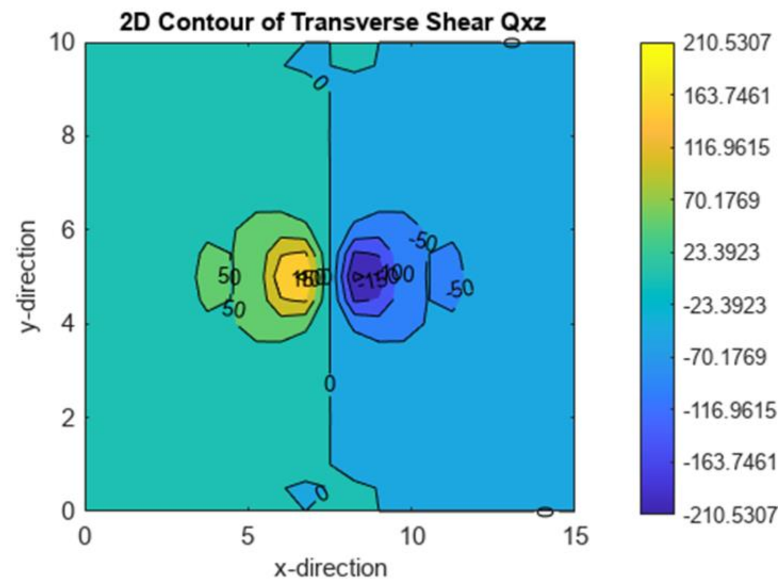




Sandwich Plate under Partial Pressure







3P COMPOSITES