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Bending Analysis of Simply Supported Anisotropic Laminated Composite Plates

3P COMPOSITES

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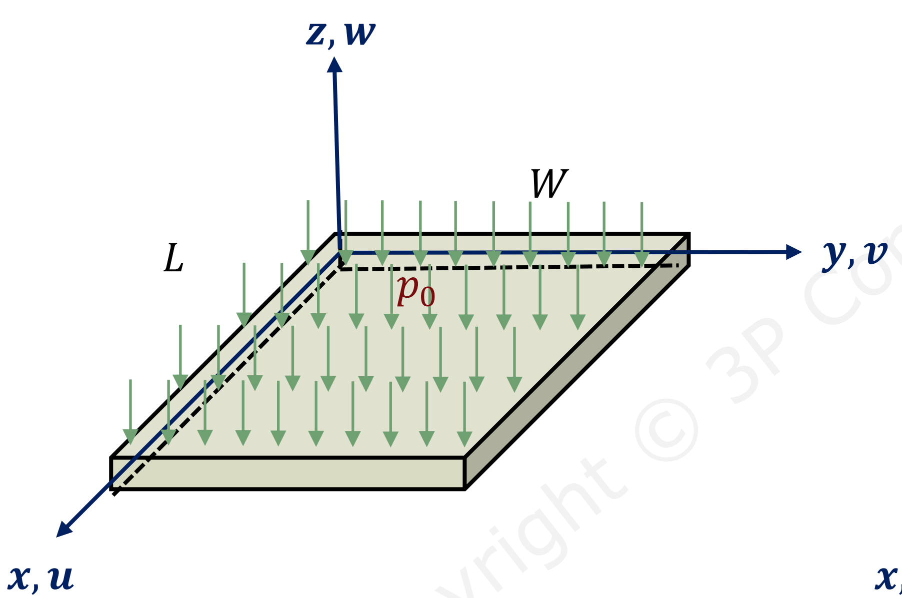
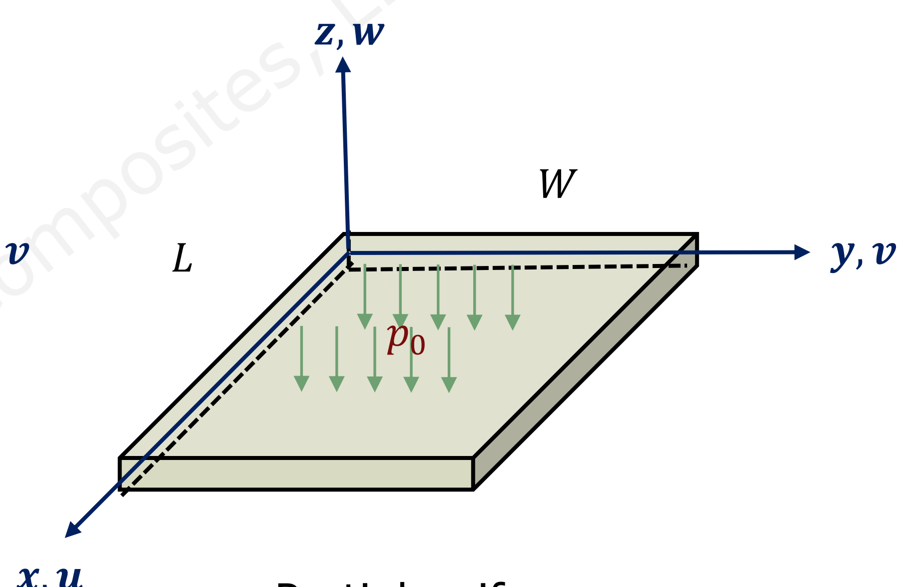
Contents: 3pcsolver002

Overview

❖ 3pcsolver002 performs bending analysis of simply-supported anisotropic composite laminates subjected to transverse loads. Simply-supported boundary condition is most widely used in the analysis of plates and shells. Four types of transverse loading as shown below are considered:

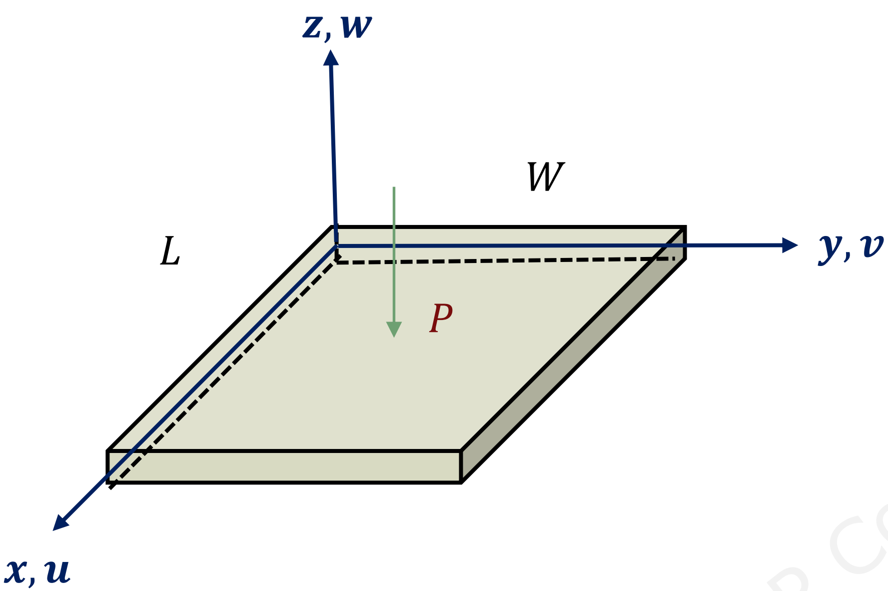


Uniform Pressure p_0

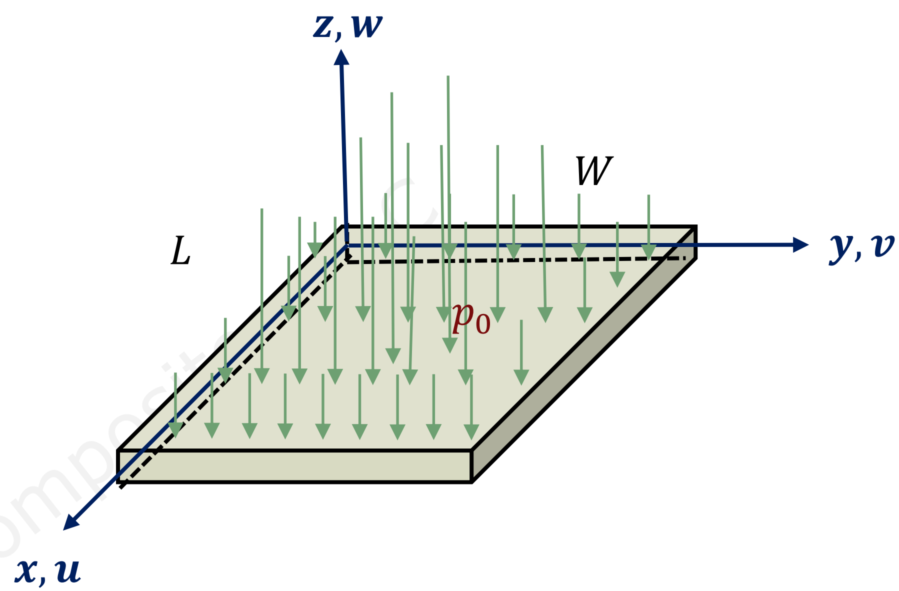


Partial uniform Pressure p_0

Overview



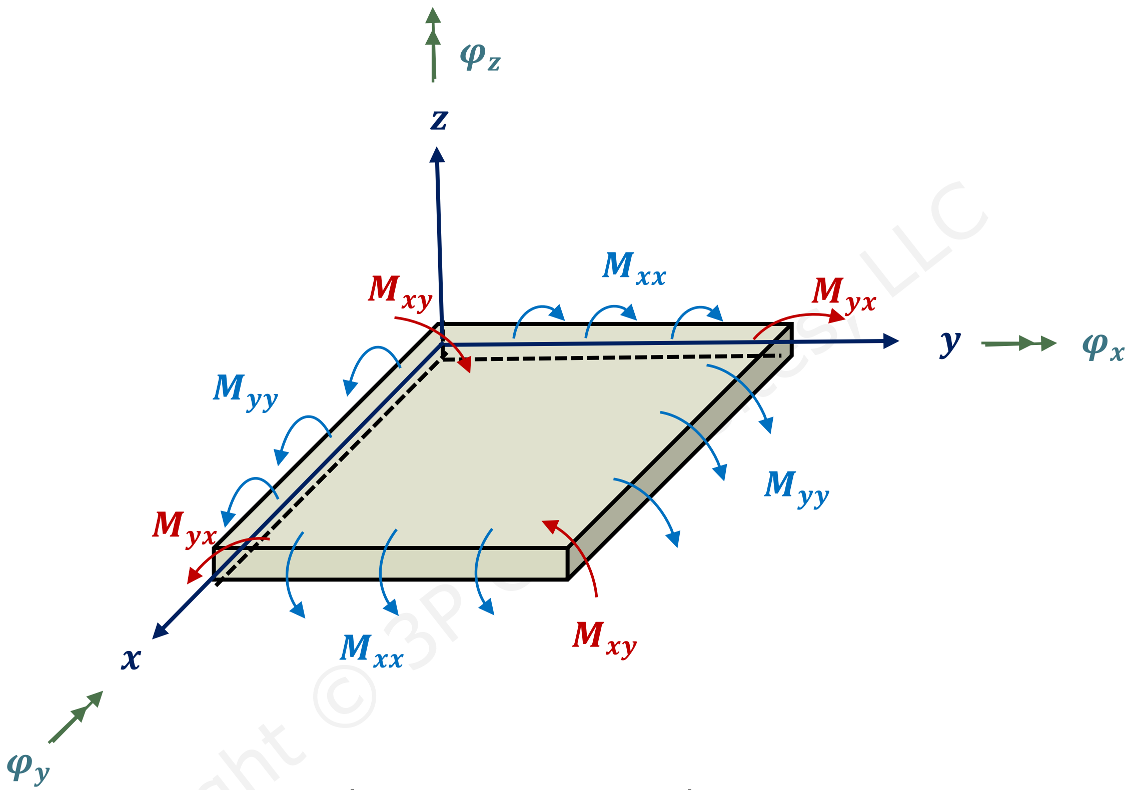
Concentrated Force P



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 plies or laminae in the laminate are laid-up or stacked from bottom-to-top. Hence, the positive transverse displacement w_0 would provide positive bending moments M_{xx} and M_{yy} resulting in tension in the topmost ply and compression in the bottommost ply. Next Slide shows positive sign conventions of plate rotations and moments

Overview



In-plane Moment resultants
(Moment per unit Length)

Applications

- Bending analysis performed by the 3pcsolver002 solver is applicable to laminates built-up (or fabricated) from a LAMINA that
  - has any kind of FIBER such as boron, carbon, graphite, glass, Kevlar, Aramid, polyester, natural fibers, etc.,
  - is in any type of broad form such as short and long continuous, unidirectional, bi-directional 2D textile weaves like plain weave, twill and harness, biaxial and triaxial braids, chopped random fibers, non-crimp, nonwoven fabrics, etc.
  - Is impregnated with any RESIN/MATRIX, thermoset or thermoplastic systems such as epoxy, polyester, vinyl ester, polyurethane, phenolic, cyanate ester, bis-maleimide, polyimides, benzoxazine, Acrylic, ABS, Polylactic acid PLA, Polybenzimidazole PBI, Polyether sulfone PES, Polyoxymethylene POM, Polyether ether ketone PEEK, Polyetherimide PEI, Polyphenylene oxide PPO, Polyphenylene sulfide PPS, Polystyrene PS, Polypropylene PP, Polyvinyl chloride PVC, Teflon PTFE, etc.
  - is cured using any MANUFACTURING PROCESS such as Autoclave, Resin Transfer Molding like VARTM, SQRTM, RIM, SRIM, Filament Winding, Pultrusion, Compression Molding, Wet-lay up, etc.

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

Theoretical Background

- **3pcsolver002** solver is based on First-Order Shear Deformation Laminated Plate Theory (Mindlin Type). Spatial distributions of displacements $\boldsymbol{u}$, $\boldsymbol{v}$ and $\boldsymbol{w}$, and rotations $\boldsymbol{\varphi_x}$ and $\boldsymbol{\varphi_y}$ of the plate's reference surface are assumed using double Fourier series satisfying the kinematic boundary conditions at all four simply-supported edges of the laminated plate exactly. Principle of virtual work and Ritz analysis procedure are used to obtain a highly coupled system of algebraic equations for transverse bending of fully anisotropic laminated 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 laminate A_{ij}, B_{ij} and D_{ij}. 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 laminated plate. P_{mn} are the known coefficients of the applied transverse loading

Theoretical Background

- Given the lamina/ply material properties, laminate stack-up and its dimensions, **3pcsolver002** solver calculates displacements, rotations, in-plane and transverse force resultants, and moment resultants for an anisotropic laminated plate subjected to any of the four types of applied transverse loading discussed earlier

- The **3pcsolver002** is perhaps the first solver which is based on FSDT of laminated plates, employs a closed-form Ritz solution procedure, and considers the fully anisotropic laminate effects. That is, 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 transverse bending analysis of laminated composite plates. Most closed-form analyses neglect these coupling effects due to the complexity in deriving the system of equations, and hence, assume the laminated plates as being specially orthotropic (i.e. $A_{i6} = B_{ij} = D_{i6} = 0, i = 1,2, j = 1,2,6)$.

- 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 **3pcsolver002** 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 material systems, ply orientations, laminate stack ups, laminate 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 various types of laminate stiffness couplings on transverse bending of anisotropic laminated composite plates

- Details of the theoretical approach along with numerous verification and application examples are available in the training module **3pcmodule002**

Inputs

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

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

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

Inputs: Materials

❖ Material Properties:

In the SI system, MPa and mm or Pa and m, and in the US system Msi and in are used to input the orthotropic lamina Moduli E_1, E_2, G_{12}, G_{13} and G_{23}. ν_{12} is major Poison's ratio. 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}	
1	0	0	0	0	0	0	+ −
	MUST BE +VE REAL	MUST BE +VE REAL	MUST BE +VE REAL	MUST BE +VE REAL	MUST BE +VE REAL	MUST BE +VE REAL	

Inputs: Plies

❖ Plies/Laminae:

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

Plies

ID	Angle (deg)	Material	Thickness
1	0	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: Laminates

❖ Laminates:

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

Laminates

ID	Stacking Sequence	Stacking Sequence (Angle)	Offset		
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	+	–

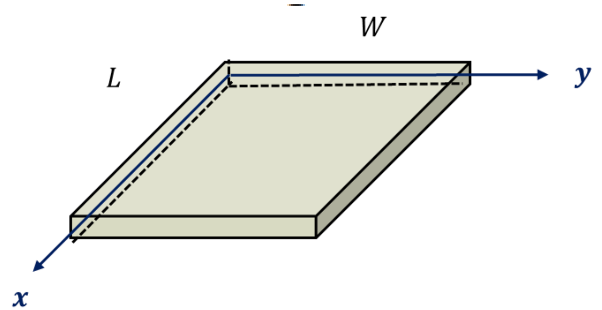
Inputs: Panels

❖ Panels:

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

Panels

ID	Length	Width	Laminate		
1	10	10	1	+	−
2	10	10	2	+	−
3	10	10	3	+	−
4	10	10	4	+	−



Inputs: Loads

❖ **Loads:**

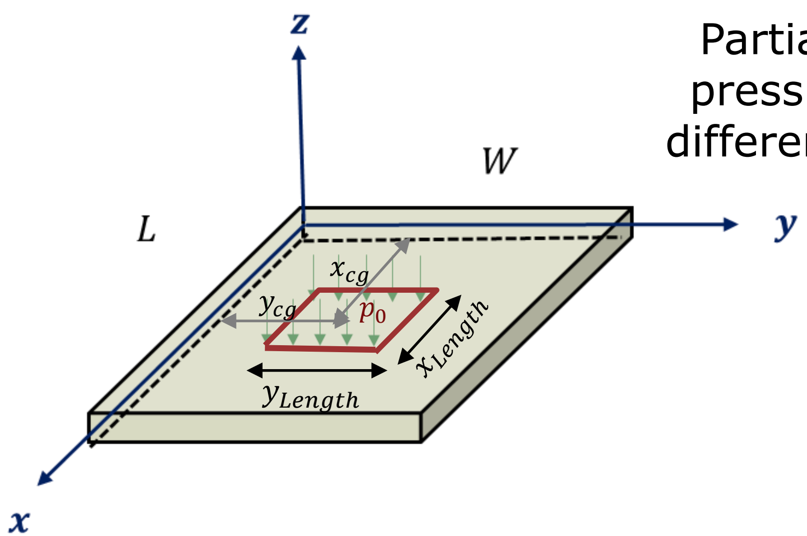
As mentioned earlier (see overview Section), four types of transverse loads can be applied to the panels. They are (i) Uniform Pressure, (ii) Partial Uniform Pressure, (iii) Point Load, and (iv) Sinusoidal Pressure.

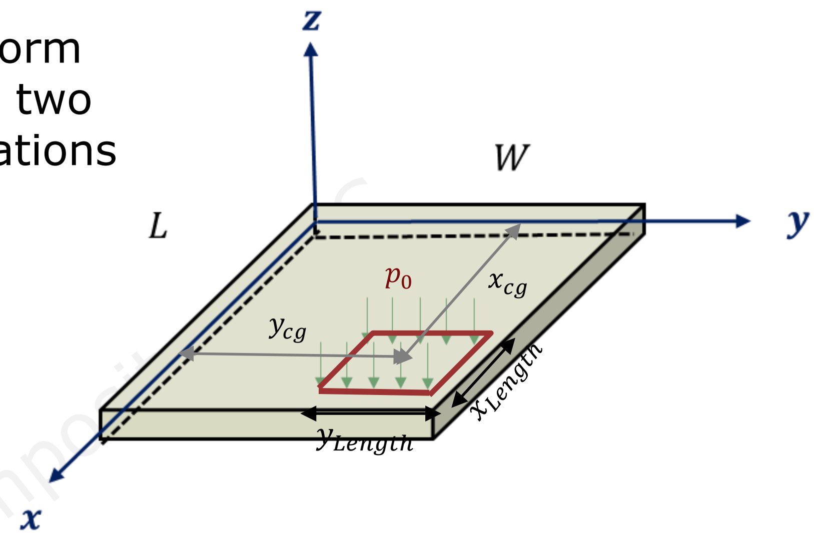
- Uniform or Sinusoidal pressure loading acts over the entire plate (or panel) and can be easily defined by providing the magnitude p_0 (force per unit area) and the direction of the load. Positive value of p_0 means the pressure is acting in the positive $z-$ direction, or vice versa.

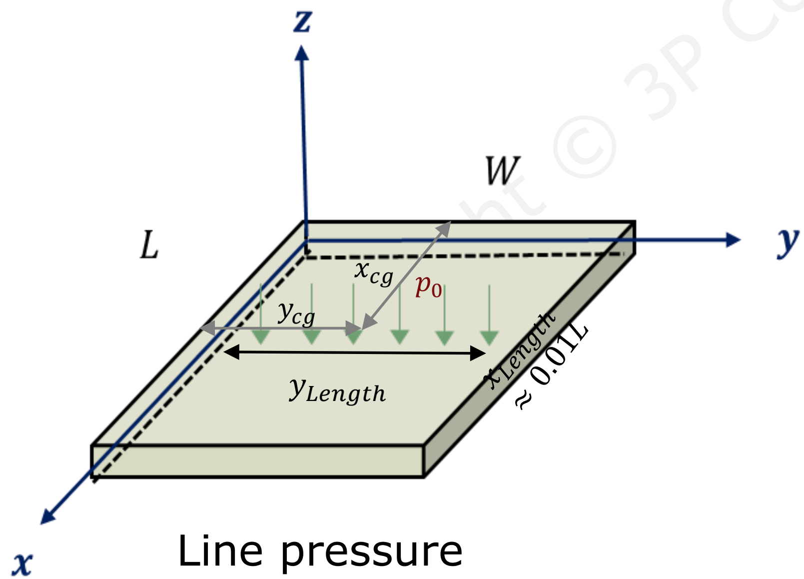
- Partial uniform pressure loading can act on a part of the panel in its domain and is defined by providing the magnitude p_0 (force per unit area),the direction of the load, the area (or patch) of the plate on which it is applied. In order to define the location and area of the partial surface over 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

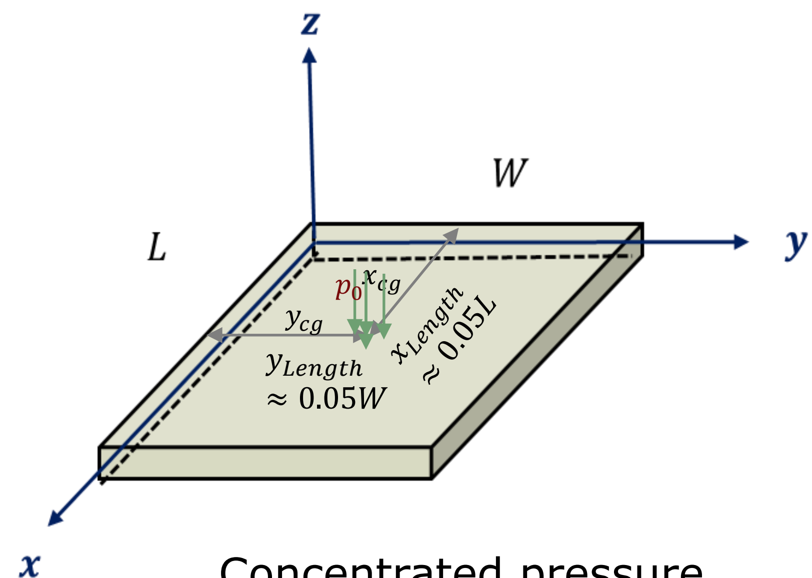
Partial uniform pressure at two different locations







Line pressure

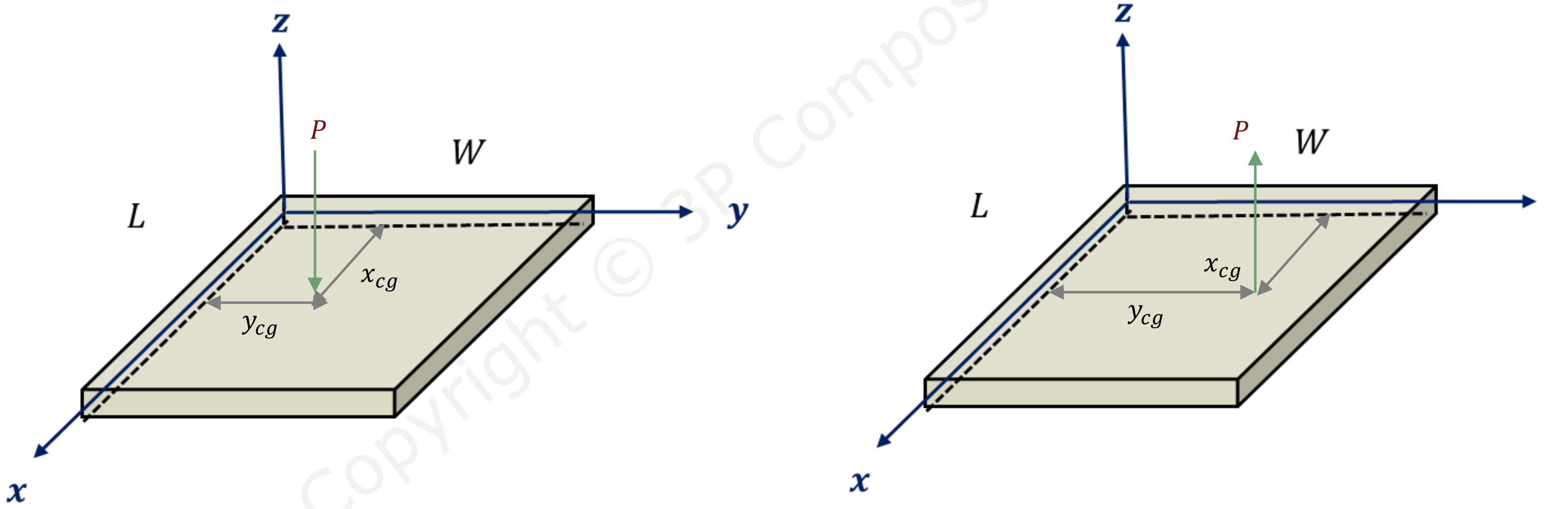


Concentrated pressure

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:



Inputs: Loads

❖ Loads:

Single or multiple panels (or laminates) can be 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 laminated anisotropic composite 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	+ −

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Inputs: Analysis Options

❖ Analysis Options:

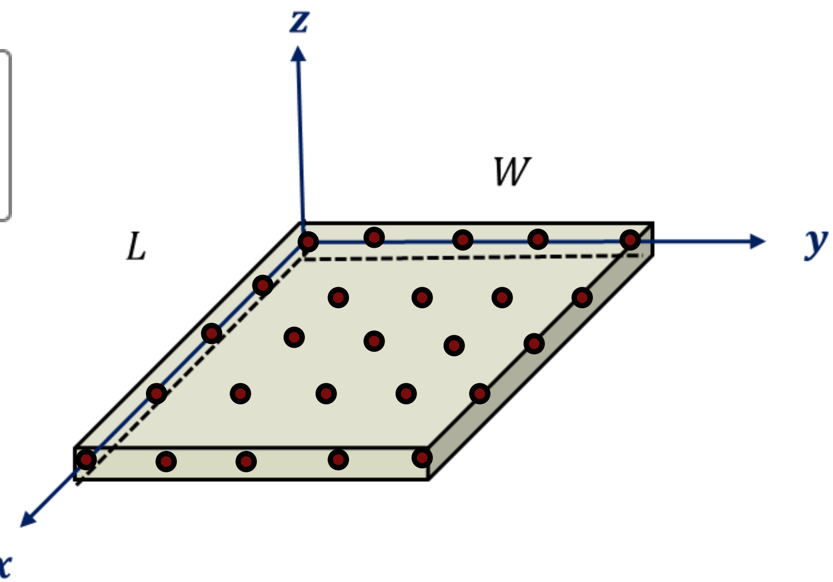
User has the option to define the number of terms in Fourier series solution of the solver. By default, $M = N = 8$ is assumed. $M = N$ can be varied from 2 to 21

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). Maximum 25×25 grid can be assumed

Default analysis options are also shown below:

Analysis Options

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



Outputs

❖ Analysis Outputs:

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

Submit

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

Output

```
3pc-solver002, v1.3b3

LOADS ID  PANEL ID
1         1

PANEL GEOMETRY
LENGTH: 10.00
WIDTH : 10.00

LOADS DESCRIPTION
TYPE: UNIFORM PRESSURE
p0: 0.05

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:

- Panel Geometry and Type of Transverse Loading
- Terms in Fourier Series solution
- Number of Grid Points selected to get output information
- Material Properties and Laminate Information
- Laminate [A], [B], [D] stiffness matrices
- Grid Points coordinates x and y , Displacements u, v and w, Rotations φ_x and φ_y, 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}

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

- Laminate [A] stiffness matrices N/m or N/mm or lb/in
- Laminate [B] stiffness matrices N-m/m or N-mm/mm or lb-in/in
- Laminate [D] stiffness matrices N-m or N-mm or lb-in
- Effective 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
- Plate Force resultants in N/m, N/mm or lb/in and Plate Moment resultants in N-m/m, N-mm/mm or lb-in/in

A typical output is shown below:

Output Text

3pc-solver002, v1.3b3

LOADS ID PANEL ID
1 1

PANEL GEOMETRY
LENGTH: 10.00
WIDTH : 10.00

LOADS DESCRIPTION
TYPE: UNIFORM PRESSURE p0: 0.05

ANALYSIS OPTIONS
m = 8
n = 8

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

MATERIAL PROPERTIES

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

LAMINATE GEOMETRY
STACKING SEQUENCE (PLY ANG): [+45.0 , -45.0 , +45.0 , -45.0]
STACKING SEQUENCE (PLY MAT): [aiaa-2009 , aiaa-2009 , aiaa-2009 , aiaa-2009]
TOTAL THICKNESS: 0.0210
OFFSET: 0.0000

LAMINATE PROPERTIES
A MATRIX

+127080.48	+90540.48	+0.00
+90540.48	+127080.48	+0.00
+0.00	+0.00	+98649.19

Output Text

A MATRIX - TRANSVERSE SHEAR

+15855.00	+0.00
+0.00	+15855.00

B MATRIX

+0.00	+0.00	-227.84
+0.00	+0.00	-227.84
-227.84	-227.84	+0.00

D MATRIX

+4.67	+3.33	+0.00
+3.33	+4.67	+0.00
+0.00	+0.00	+3.63

LAMINATE INPLANE AND FLEXURAL ENGINEERING CONSTANTS

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

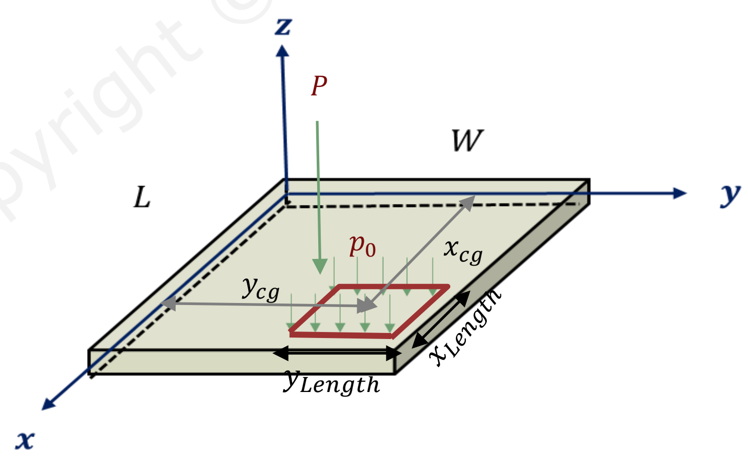
GRID POINTS, DISPLACEMENTS, ROTATIONS, FORCES, AND MOMENTS

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	+15.0020	+15.0020	+19.7427	-0.0456	-0.0456	-0.2387	+0.0000	+0.0000
2.5000	0.0000	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	-6.7600e-02	+8.6694	+8.6694	-2.5604	+0.0059	+0.0059	-0.1379	+0.1255	+0.0000
5.0000	0.0000	+0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	-9.1700e-02	+0.0000	+0.0000	-6.3573	+0.0147	+0.0147	-0.0000	+0.1443	+0.0000
7.5000	0.0000	+0.0000e+00	-0.0000e+00	+0.0000e+00	+0.0000e+00	-6.7600e-02	-8.6694	-8.6694	-2.5604	+0.0059	+0.0059	+0.1379	+0.1255	+0.0000
10.0000	0.0000	+0.0000e+00	-0.0000e+00	+0.0000e+00	+0.0000e+00	-0.0000e+00	-15.0020	-15.0020	+19.7427	-0.0456	-0.0456	+0.2387	+0.0000	+0.0000
0.0000	2.5000	+0.0000e+00	+0.0000e+00	+0.0000e+00	-6.7600e-02	+0.0000e+00	+8.6694	+8.6694	-2.5604	+0.0059	+0.0059	-0.1379	+0.0000	+0.1255
2.5000	2.5000	-0.0000e+00	-0.0000e+00	+1.4630e-01	-4.2600e-02	-4.2600e-02	+2.2499	+2.2499	-6.9978	+0.1276	+0.1276	-0.0858	+0.0510	+0.0510
5.0000	2.5000	-0.0000e+00	+0.0000e+00	+2.0040e-01	-0.0000e+00	-5.9100e-02	-0.0000	-0.0000	-7.9307	+0.1532	+0.1590	-0.0000	+0.0637	+0.0000
7.5000	2.5000	-0.0000e+00	+0.0000e+00	+1.4630e-01	+4.2600e-02	-4.2600e-02	-2.2499	-2.2499	-6.9978	+0.1276	+0.1276	+0.0858	+0.0510	-0.0510
10.0000	2.5000	+0.0000e+00	+0.0000e+00	+0.0000e+00	+6.7600e-02	-0.0000e+00	-8.6694	-8.6694	-2.5604	+0.0059	+0.0059	+0.1379	+0.0000	-0.1255
0.0000	5.0000	+0.0000e+00	+0.0000e+00	+0.0000e+00	-9.1700e-02	+0.0000e+00	+0.0000	+0.0000	-6.3573	+0.0147	+0.0147	-0.0000	+0.0000	+0.1443
2.5000	5.0000	+0.0000e+00	-0.0000e+00	+2.0040e-01	-5.9100e-02	-0.0000e+00	-0.0000	-0.0000	-7.9307	+0.1590	+0.1532	-0.0000	+0.0000	+0.0637
5.0000	5.0000	-0.0000e+00	-0.0000e+00	+2.7560e-01	-0.0000e+00	-0.0000e+00	-0.0000	-0.0000	-9.5370	+0.1936	+0.1936	+0.0000	+0.0000	+0.0000
7.5000	5.0000	-0.0000e+00	+0.0000e+00	+2.0040e-01	+5.9100e-02	-0.0000e+00	-0.0000	-0.0000	-7.9307	+0.1590	+0.1532	+0.0000	+0.0000	-0.0637
10.0000	5.0000	-0.0000e+00	+0.0000e+00	+0.0000e+00	+9.1700e-02	-0.0000e+00	-0.0000	-0.0000	-6.3573	+0.0147	+0.0147	+0.0000	-0.0000	-0.1443
0.0000	7.5000	-0.0000e+00	+0.0000e+00	+0.0000e+00	-6.7600e-02	+0.0000e+00	-8.6694	-8.6694	-2.5604	+0.0059	+0.0059	+0.1379	+0.0000	+0.1255
2.5000	7.5000	+0.0000e+00	-0.0000e+00	+1.4630e-01	-4.2600e-02	+4.2600e-02	-2.2499	-2.2499	-6.9978	+0.1276	+0.1276	+0.0858	-0.0510	+0.0510
5.0000	7.5000	+0.0000e+00	-0.0000e+00	+2.0040e-01	-0.0000e+00	+5.9100e-02	-0.0000	-0.0000	-7.9307	+0.1532	+0.1590	+0.0000	-0.0637	+0.0000
7.5000	7.5000	+0.0000e+00	+0.0000e+00	+1.4630e-01	+4.2600e-02	+4.2600e-02	+2.2499	+2.2499	-6.9978	+0.1276	+0.1276	-0.0858	-0.0510	-0.0510
10.0000	7.5000	-0.0000e+00	+0.0000e+00	+0.0000e+00	+6.7600e-02	+0.0000e+00	+8.6694	+8.6694	-2.5604	+0.0059	+0.0059	-0.1379	-0.0000	-0.1255
0.0000	10.0000	-0.0000e+00	+0.0000e+00	+0.0000e+00	-0.0000e+00	+0.0000e+00	-15.0020	-15.0020	+19.7427	-0.0456	-0.0456	+0.2387	+0.0000	+0.0000
2.5000	10.0000	+0.0000e+00	+0.0000e+00	+0.0000e+00	-0.0000e+00	+6.7600e-02	-8.6694	-8.6694	-2.5604	+0.0059	+0.0059	+0.1379	-0.1255	+0.0000
5.0000	10.0000	+0.0000e+00	-0.0000e+00	+0.0000e+00	-0.0000e+00	+9.1700e-02	-0.0000	-0.0000	-6.3573	+0.0147	+0.0147	+0.0000	-0.1443	-0.0000
7.5000	10.0000	+0.0000e+00	-0.0000e+00	+0.0000e+00	+0.0000e+00	+6.7600e-02	+8.6694	+8.6694	-2.5604	+0.0059	+0.0059	-0.1379	-0.1255	-0.0000
10.0000	10.0000	-0.0000e+00	-0.0000e+00	+0.0000e+00	+0.0000e+00	+0.0000e+00	+15.0020	+15.0020	+19.7427	-0.0456	-0.0456	-0.2387	-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 3pcsolver001 solver to further obtain the following:
  - Laminate strains and curvatures
  - Ply-by-ply strains and stresses
  - Laminate/Lamina Failure Indices or Margins of Safety
- Since 3pcsolver002 solver performs linear analysis, principle of superposition can be utilized to perform bending analyses of fully anisotropic laminated composite plates subjected to numerous 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
$E_1, E_2, G_{12}, G_{13}, G_{23}$ $E_x, E_y, G_{xy}, E_{fx}, E_{fy}, G_{fxy}$	$MPa\ (N/mm^2)$	$Pa\ (N/m^2)$	$Psi\ (lb/in^2)$
$\alpha_1\ ,\ \alpha_2\ ,\ \alpha_x\ ,\ \alpha_y, \alpha_{xy}$	$mm/mm/$°C	$m/m/$°C	$in/in/$°F
$\beta_1, \beta_2\ ,\ \beta_x\ ,\ \beta_y, \beta_{xy}$	$mm/mm/Kg/Kg$	$m/m/Kg/Kg$	$in/in/lb/lb$
$\sigma_{11}^T, \sigma_{11}^C, \sigma_{22}^T, \sigma_{22}^C\ \tau_{12}^S, \sigma_1, \sigma_2, \tau_{12}, \tau_{23}, \tau_{13},$ $\sigma_x, \sigma_y, \tau_{xy}, \tau_{yz}, \tau_{xz}, p_0$	$MPa\ (N/mm^2)$	$Pa\ (N/m^2)$	$Psi\ (lb/in^2)$
$\varepsilon_{11}^T, \varepsilon_{11}^C, \varepsilon_{22}^T, \varepsilon_{22}^C, \gamma_{12}, \varepsilon_1, \varepsilon_2, \gamma_{12}, \gamma_{13}, \gamma_{23}, \varepsilon_{x0},$ $\varepsilon_{y0}, \gamma_{xy0}, \gamma_{yz0}, \gamma_{xz0}\ \varepsilon_x, \varepsilon_y, \gamma_{xy}, \gamma_{yz}, \gamma_{xz}$	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]	$N-mm$	$N-m$	$lb-in$
ΔT	°C	°C	°F
ΔC	Kg/Kg	Kg/Kg	lb/lb
Ply Angle, θ	Degree	Degree	Degree
Ply or Laminate thickness or Offset or w	mm	m	in

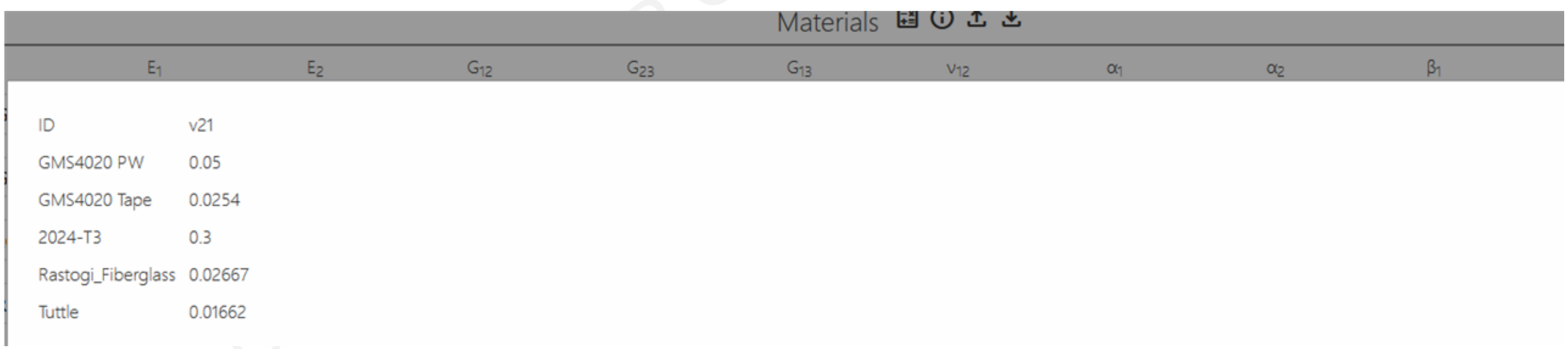
Other Features

❖ Upload/Download:

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

3P COMPOSITES
PRODUCIBILITY PERFORMANCE PROFITABILITY

General Information

- Subscription fee to access 3pcsolver002 is $39/year per for a single-login license

- Training module 3pcmodule002 supports the solver 3pcsolver002. 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 3pcsolver002 and 3pcmodule002. 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 Laminated Plates

- Lamina Properties: $E_1 = 1.8e7\ psi, E_2 = 1.6e6\ psi$; $G_{12} = G_{13} = 8.7e5\ psi$, $G_{23} = 6.4e5\ psi; \nu_{21} = 0.3, t_{ply} = 0.00525\ inch$, $\rho = 1.49 \times 10^{-4} \text{lb/in}^3$

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

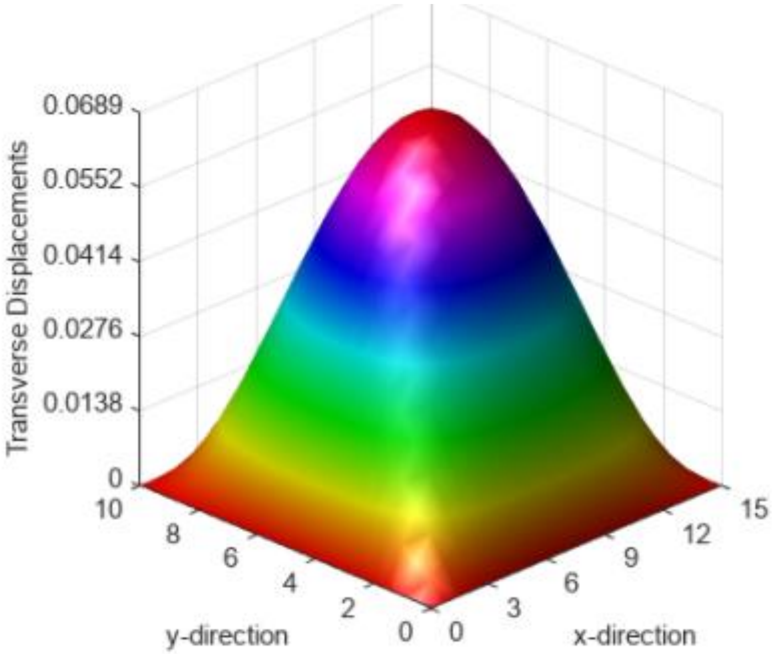
- Laminate I: $[\pm 45]_{2s}, D_{16} \neq D_{26} \neq 0$ (shows as skewed modes)
  - I: Uniform Pressure Load p_0 = 0.05 Psi
  - II: Partial Line Pressure Load p_0 = 0.005 Psi
  - III: Concentrated Load P = 5 lb

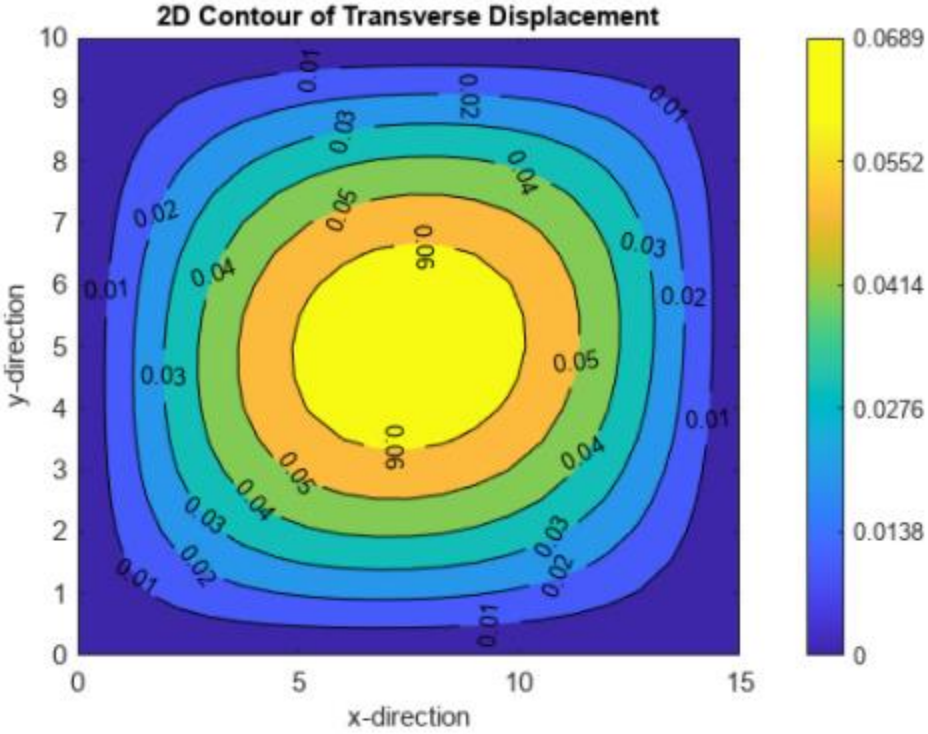
- Laminate II: $[\pm 45]_T, B_{16} \neq B_{26} \neq 0$
  - I: Uniform Pressure Load p_0 = 0.05 Psi

- Laminate III: $[0/90]_T, B_{11} \neq B_{22} \neq 0$
  - I: Uniform Pressure Load p_0 = 0.05 Psi

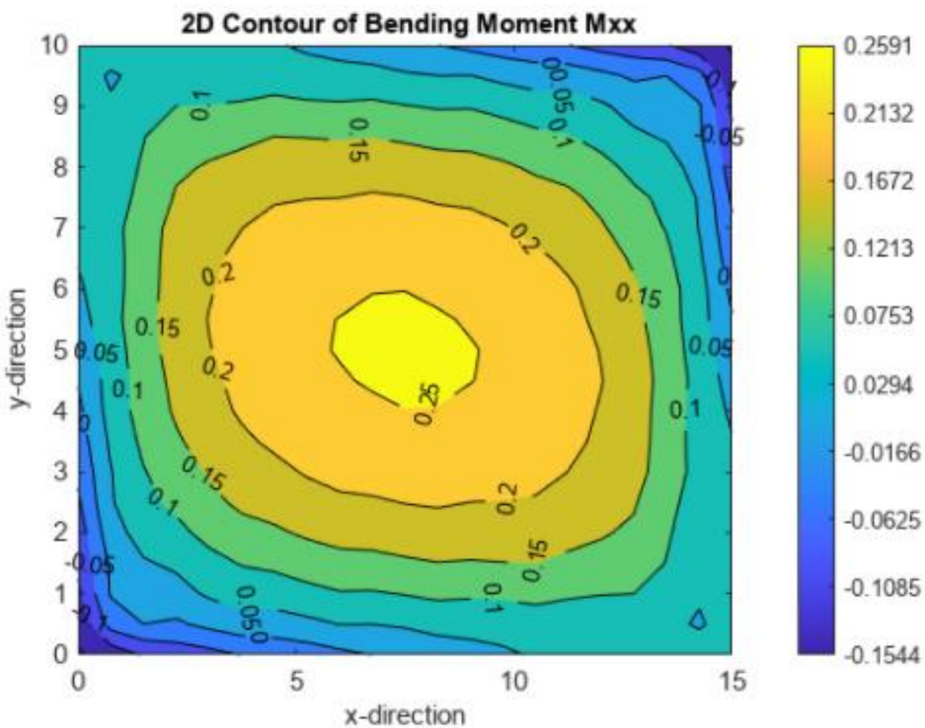
- MATLAB scripts are used to plot transverse displacement w, moment resultants M_{xx}, M_{yy} and M_{xy} and the transverse shear force resultants Q_{xz} and Q_{yz} in the laminated plate subjected to transverse loading

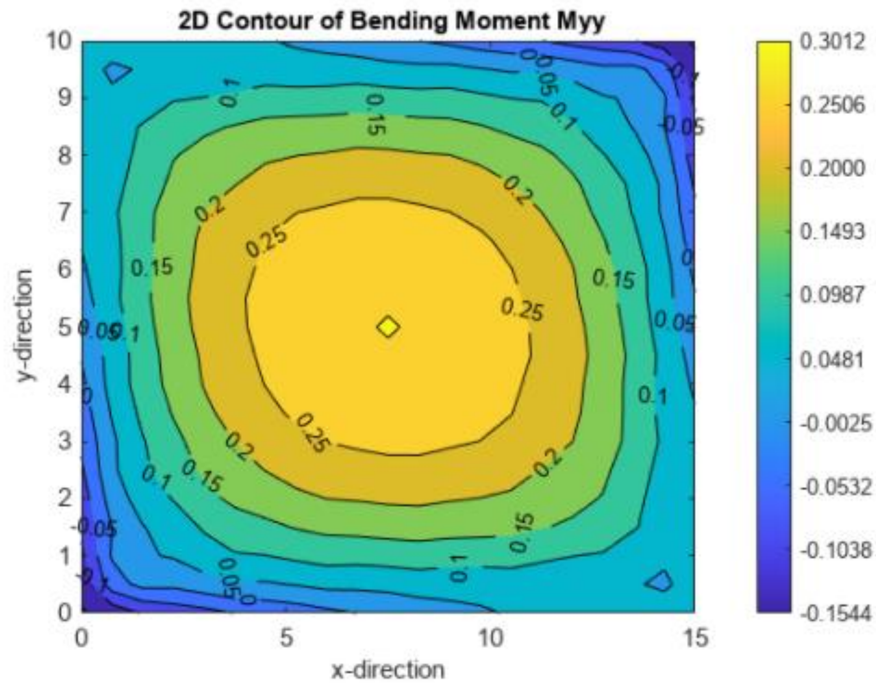
Laminate $[\pm 45]_{2s}$: Bending under Uniform Pressure





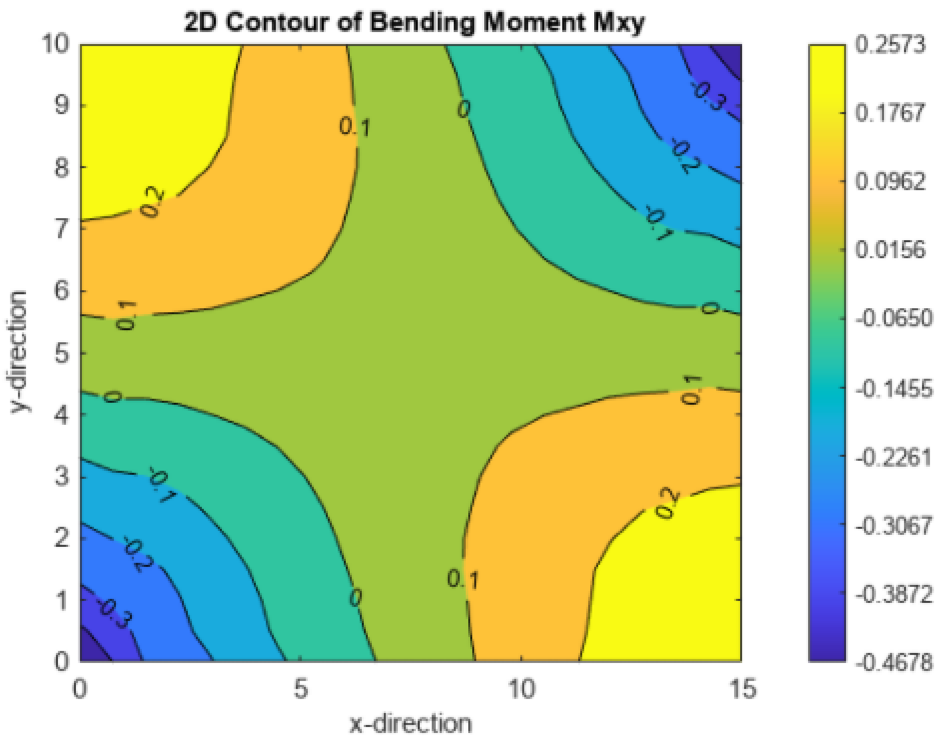
Laminate $[\pm 45]_{2s}$: Bending under Uniform Pressure

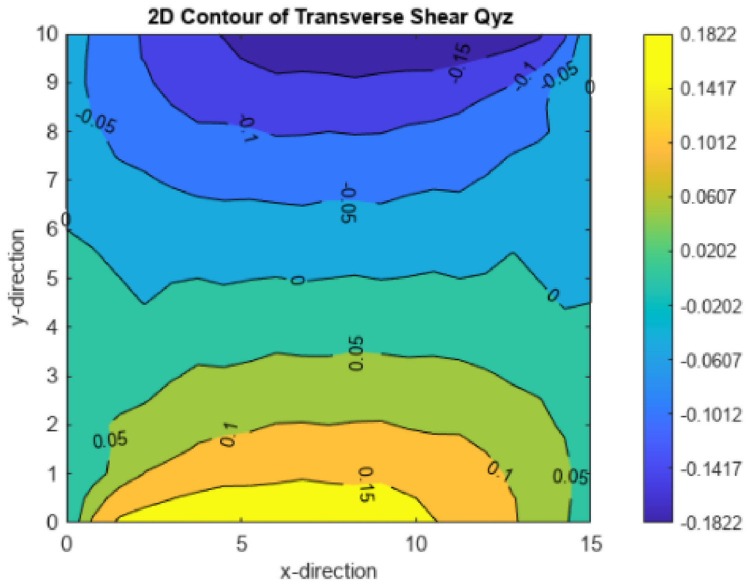


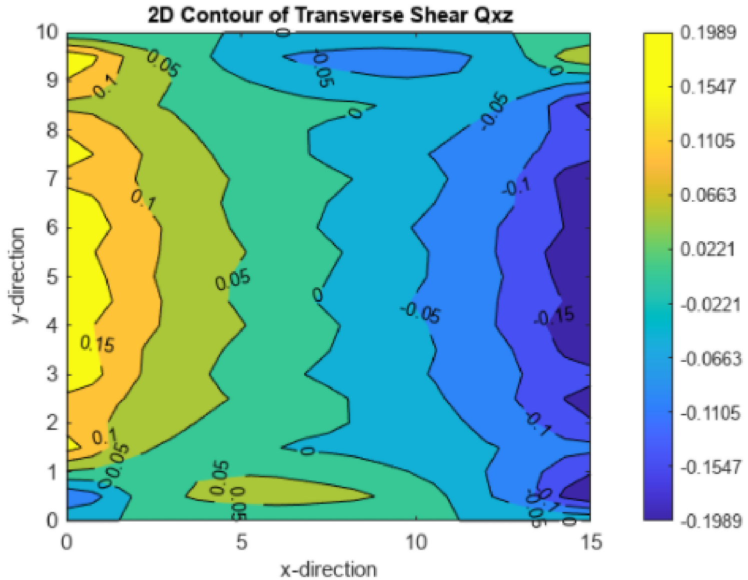


3P COMPOSITES

Laminate $[\pm 45]_{2s}$: Bending under Uniform Pressure

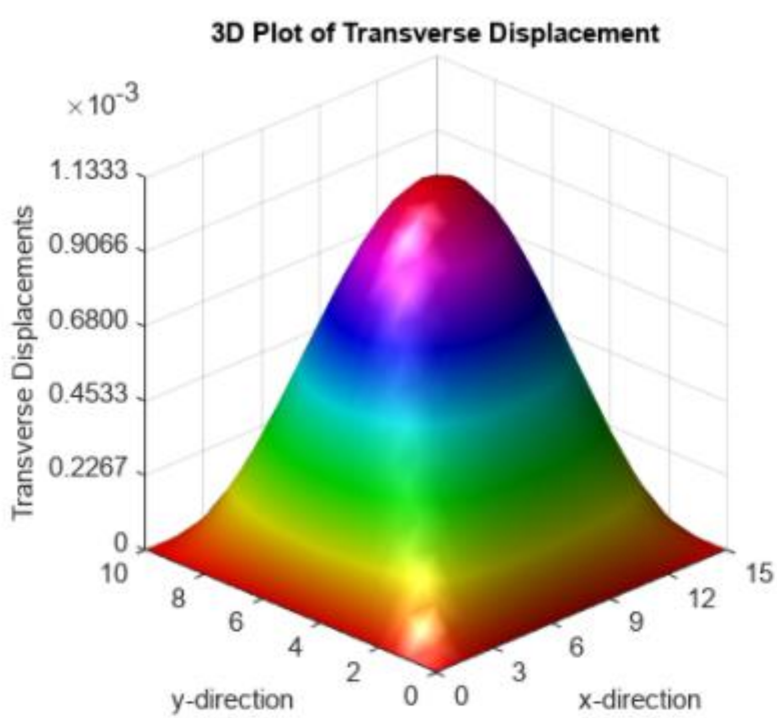


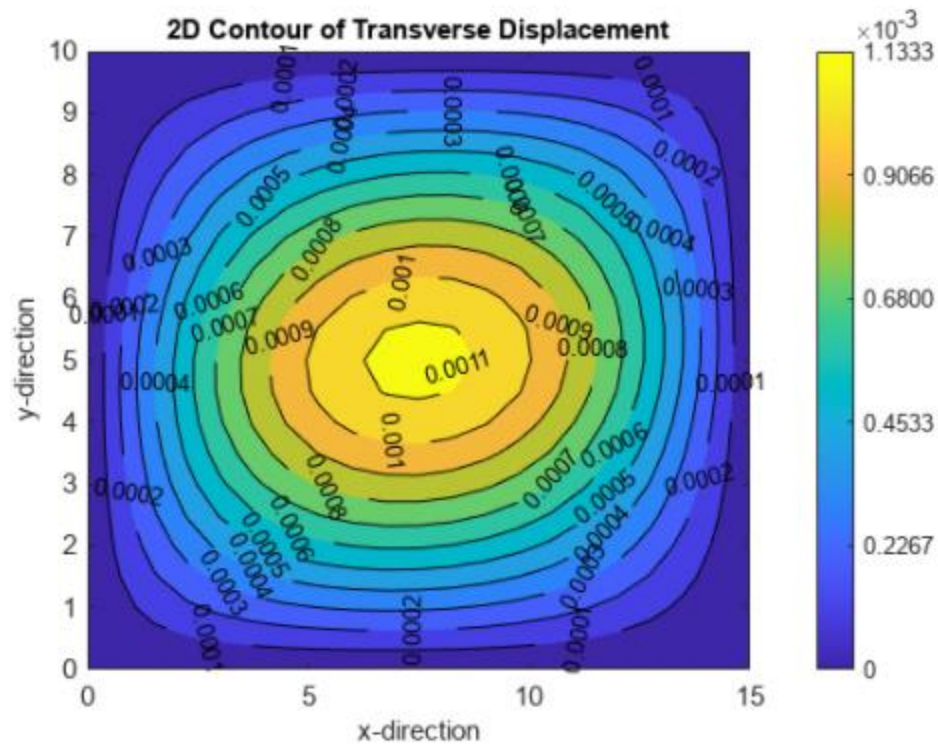




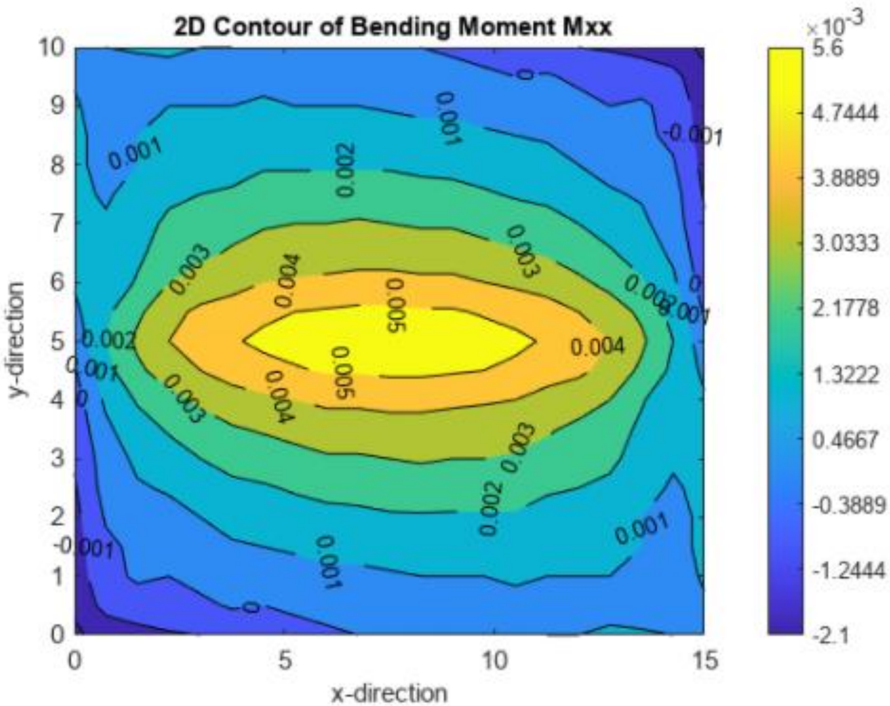
3P COMPOSITES

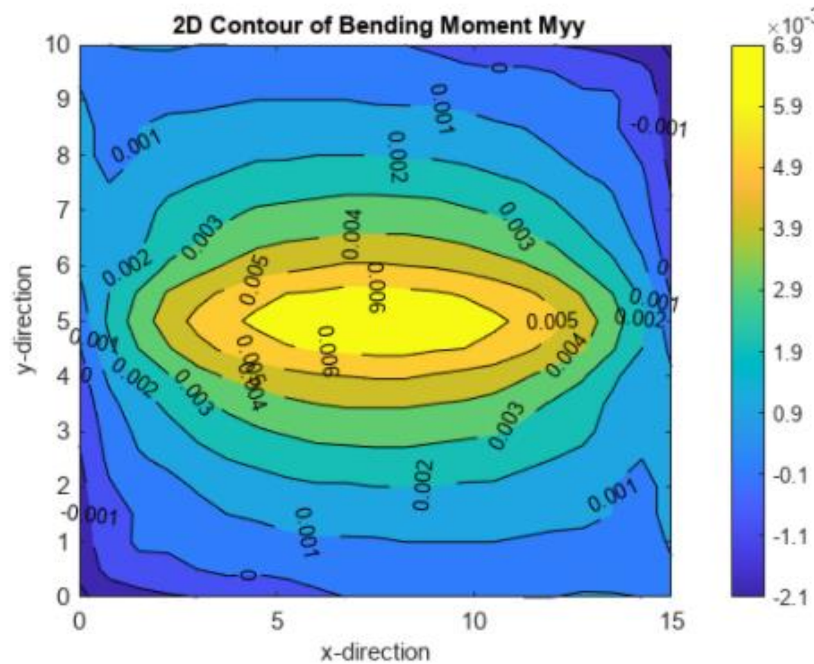
Laminate $[\pm 45]_{2s}$: Bending under Partial Pressure



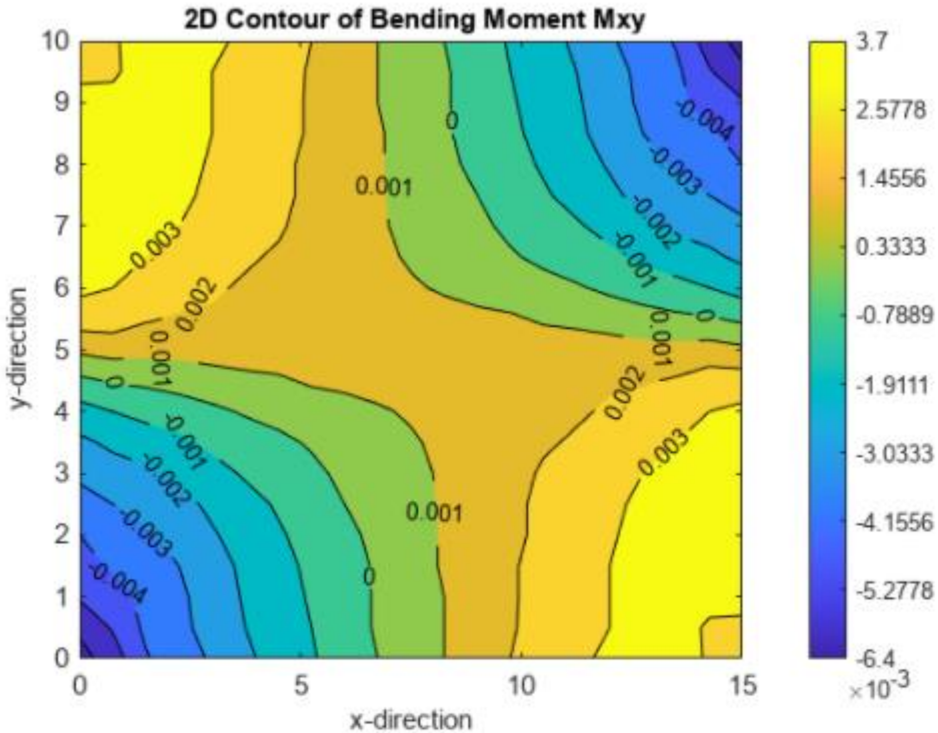


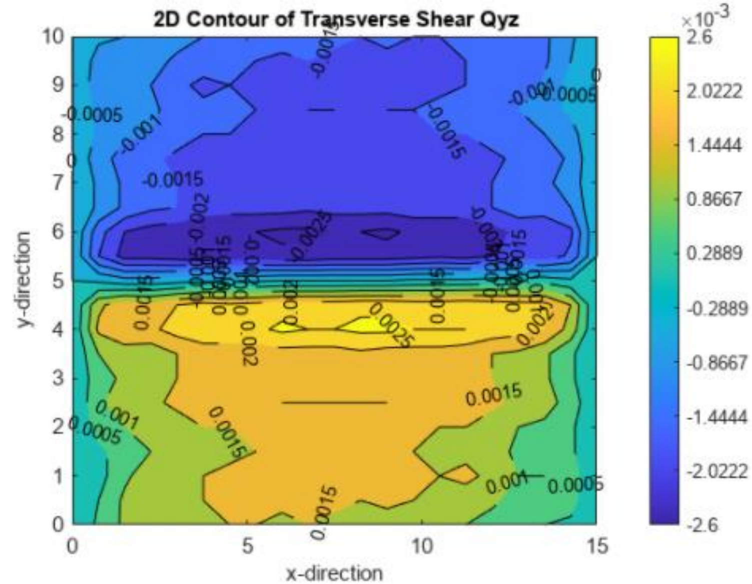
Laminate $[\pm 45]_{2s}$: Bending under Partial Pressure

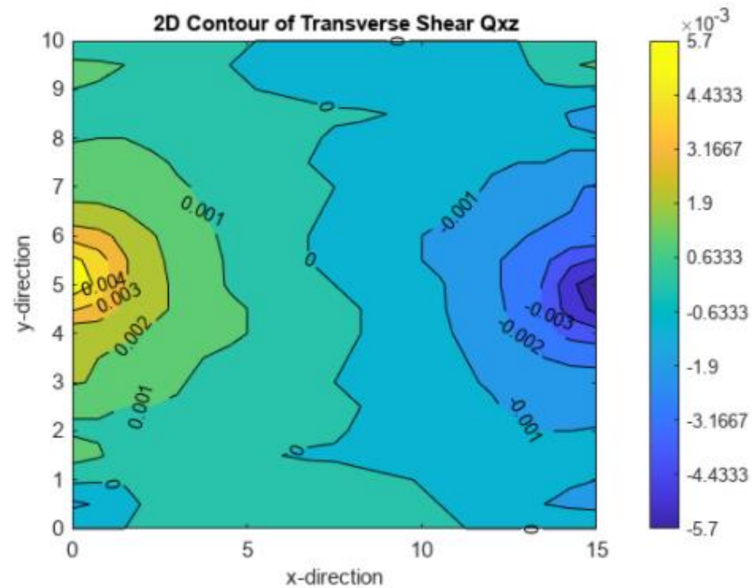




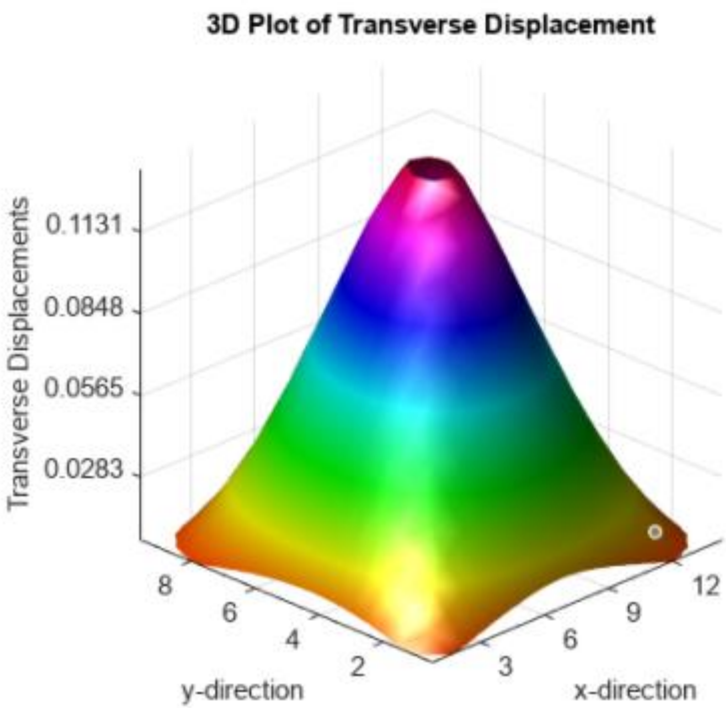
Laminate $[\pm 45]_{2s}$: Bending under Partial Pressure

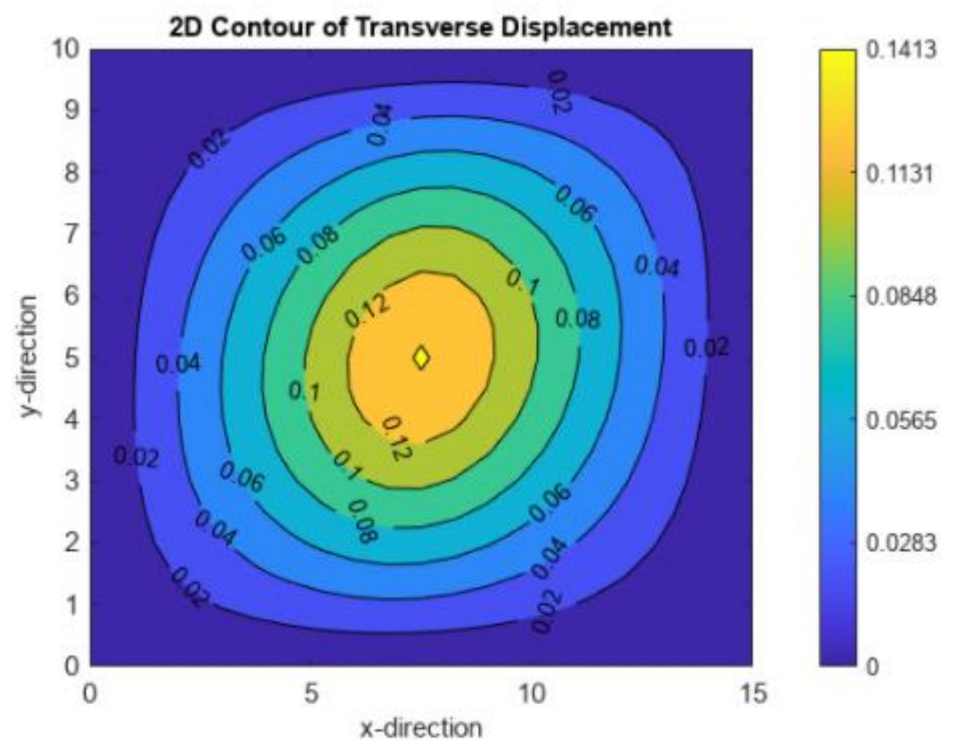




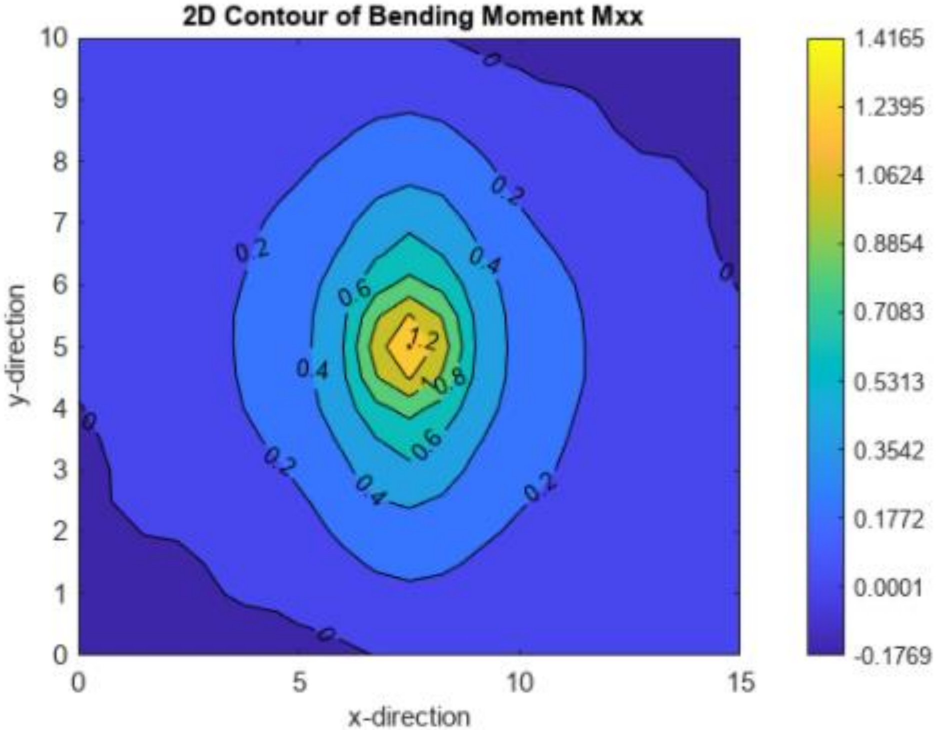


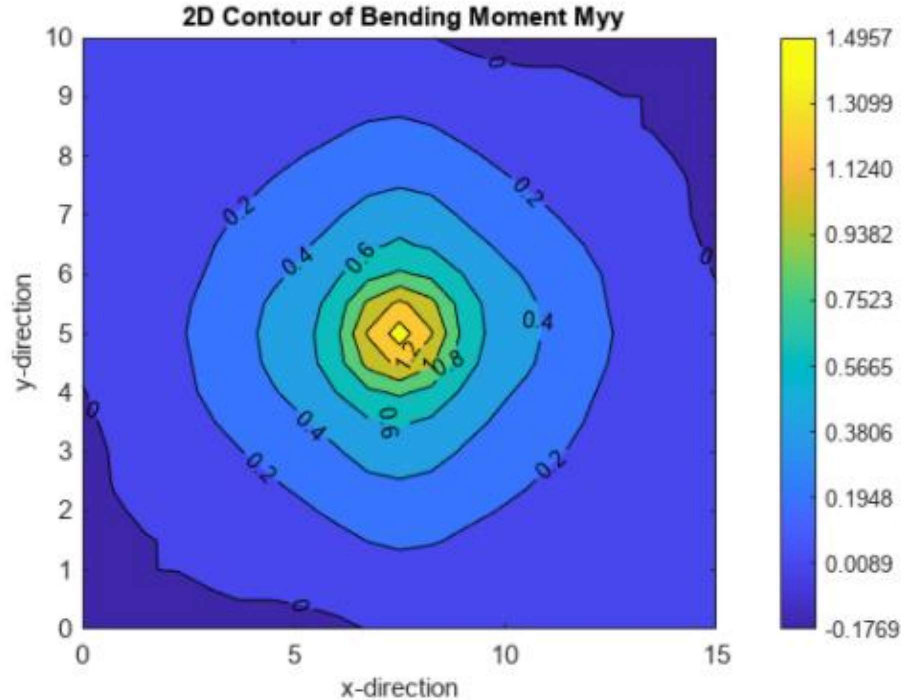
Laminate $[\pm 45]_{2s}$: Bending under Point Load



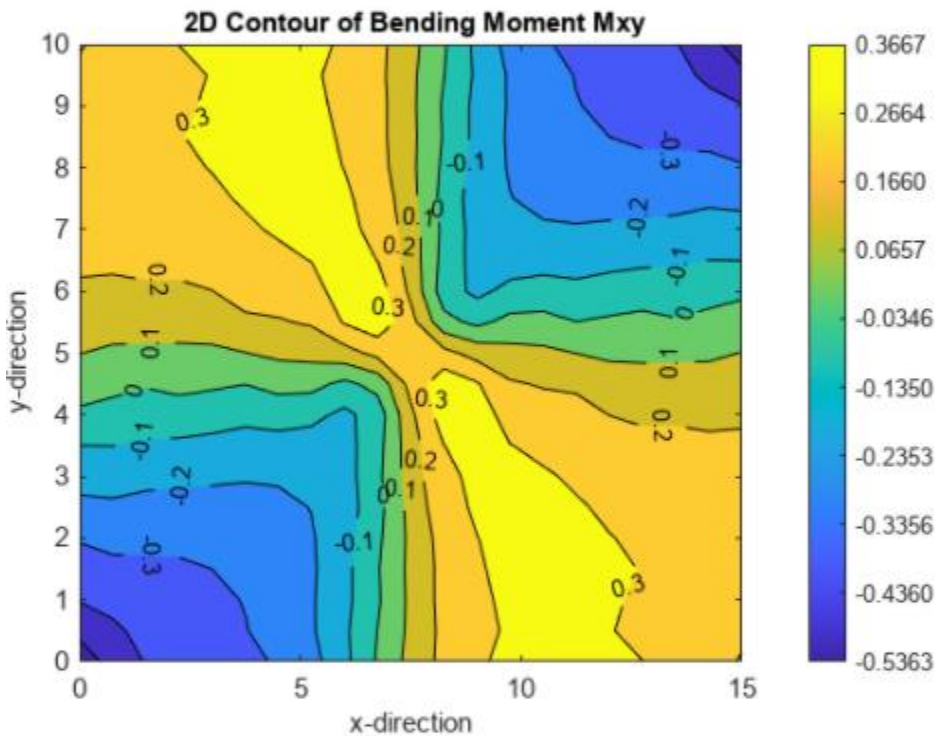


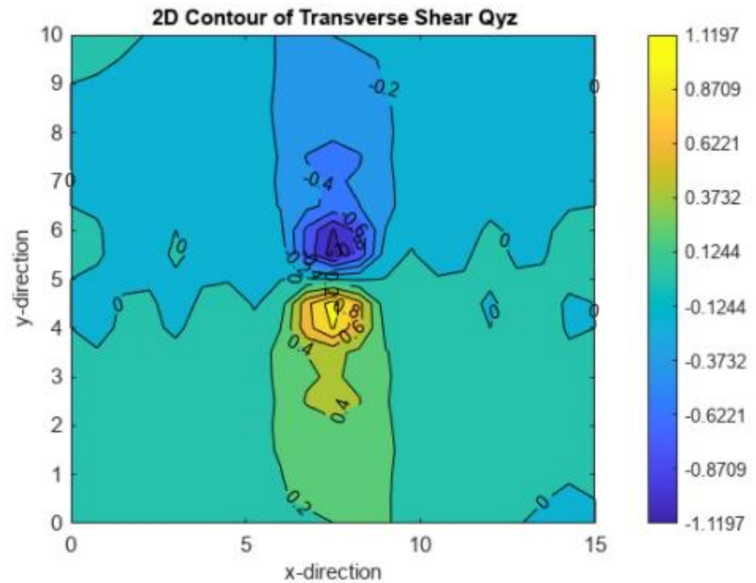
Laminate $[\pm 45]_{2s}$: Bending under Point Load

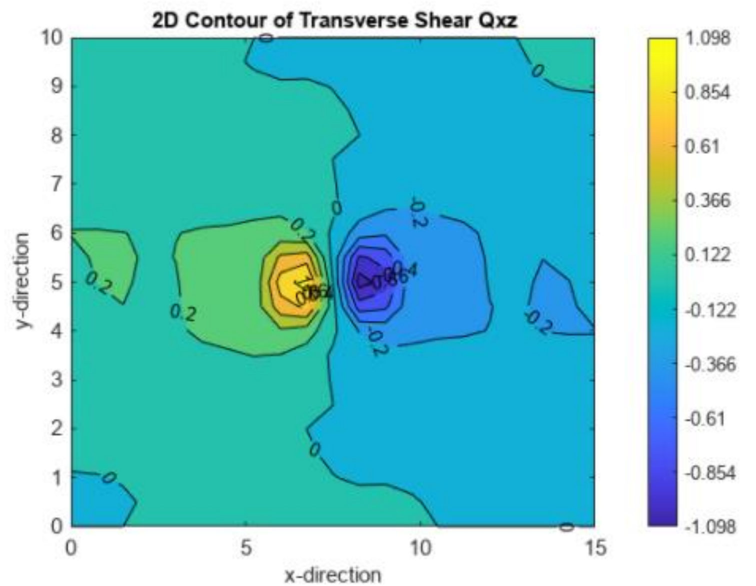




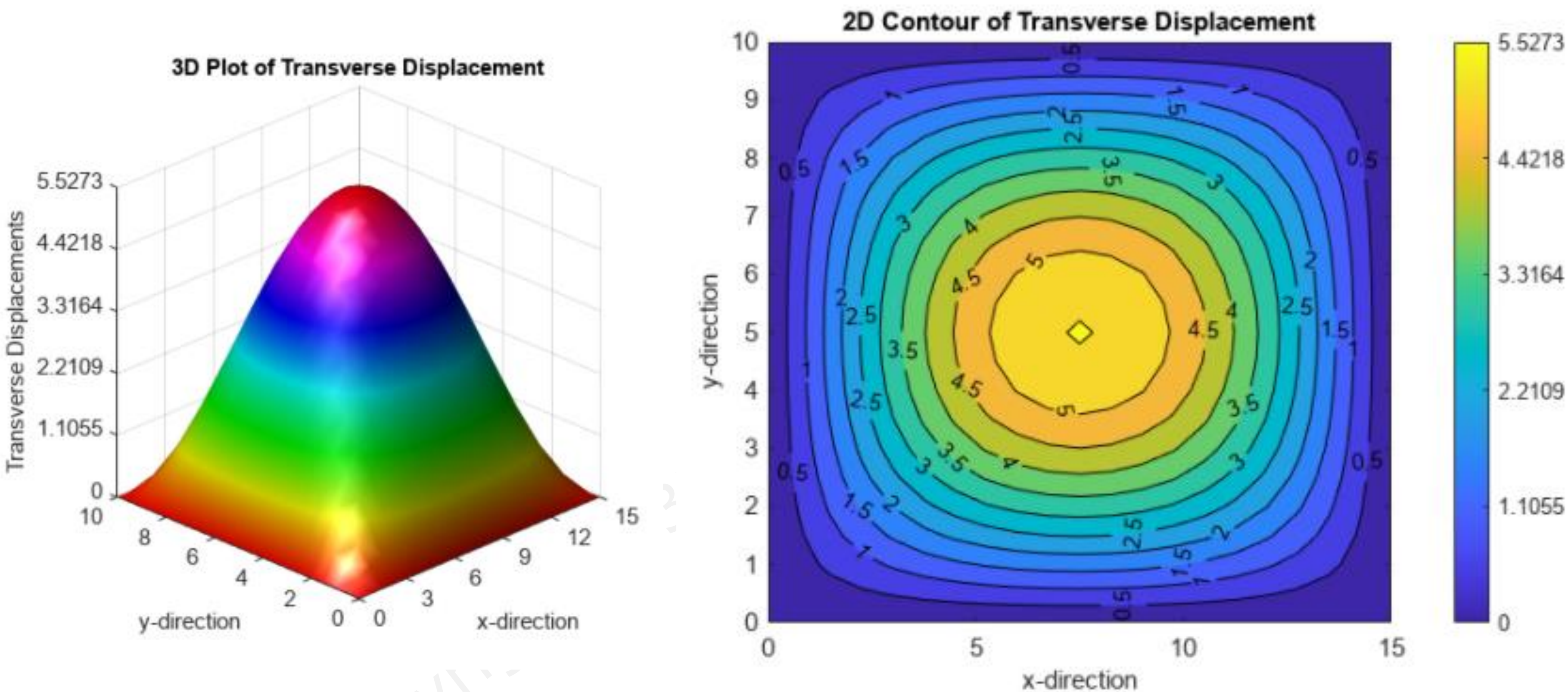
Laminate $[\pm 45]_{2s}$: Bending under Point Load



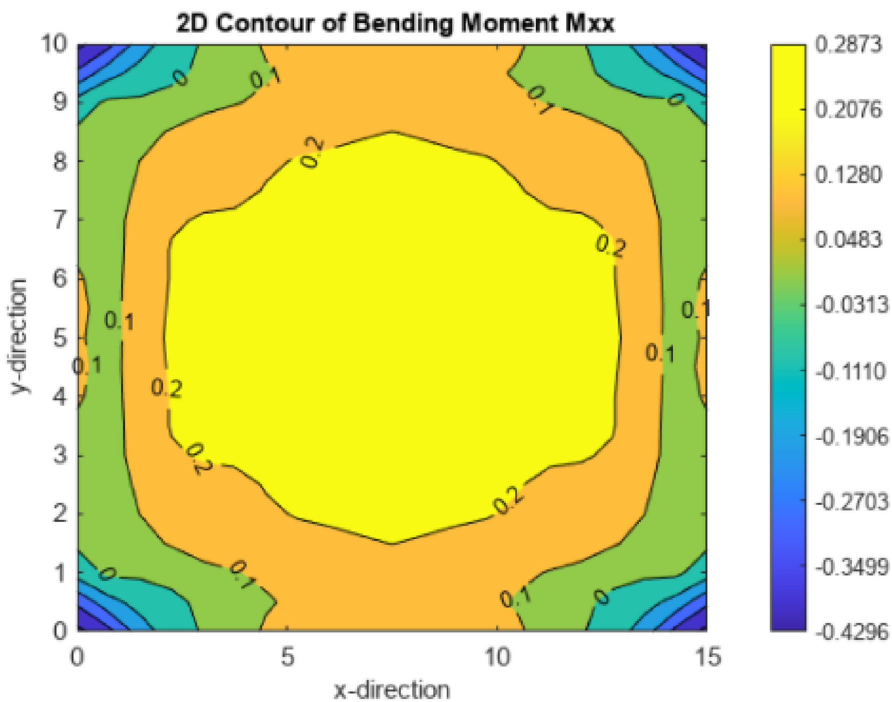


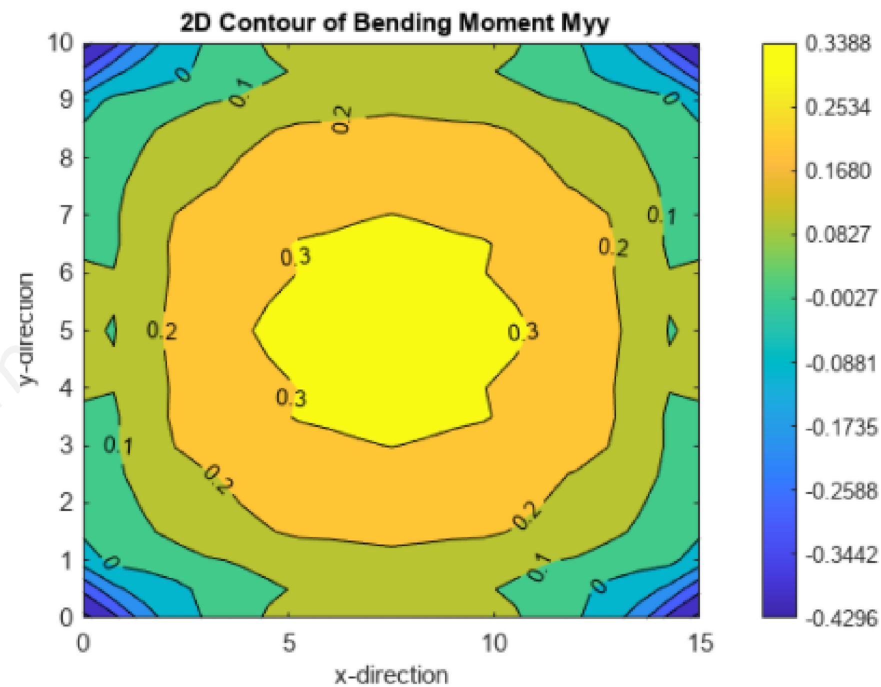


Laminate $[\pm 45]_T$: Bending under Uniform Pressure

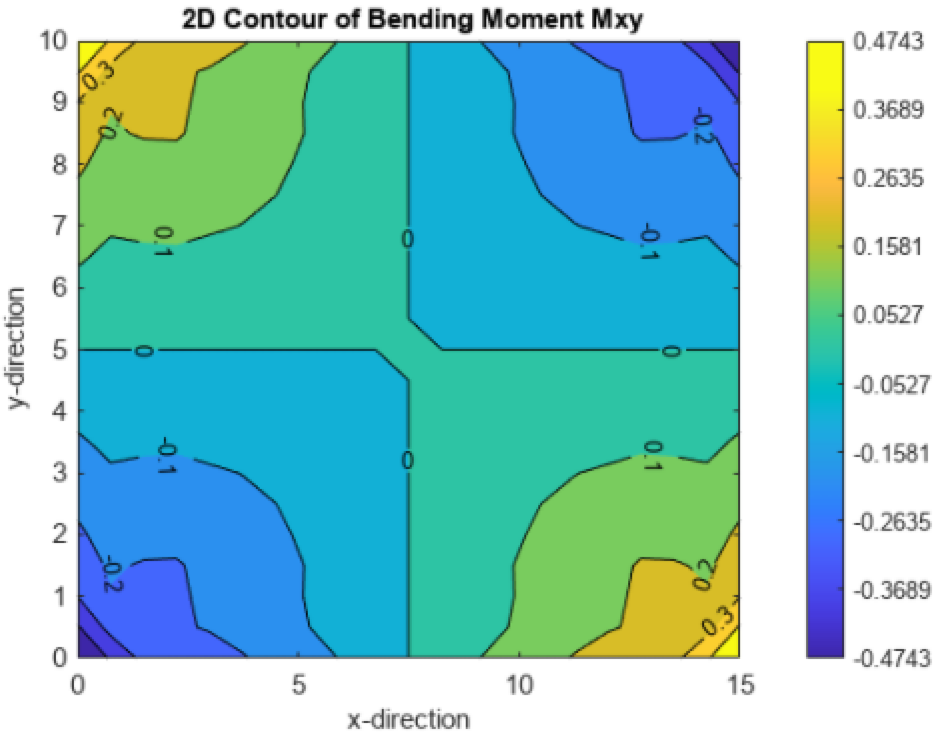


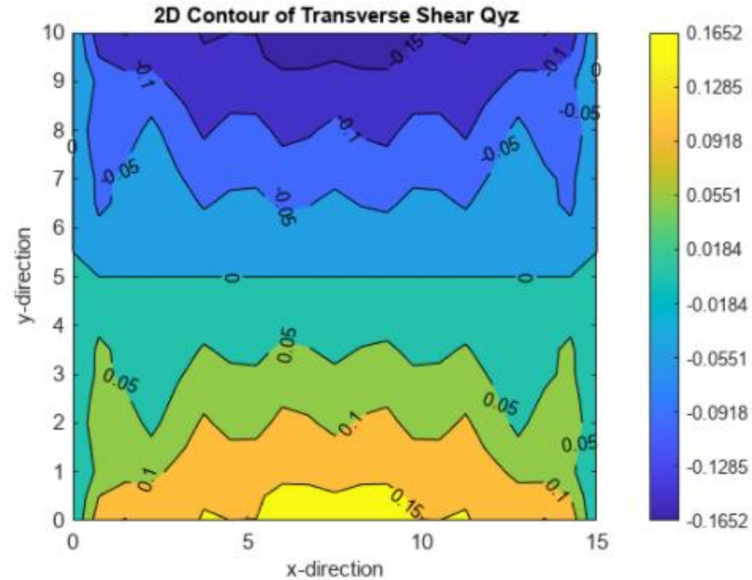
Laminate $[\pm 45]_T$: Bending under Uniform Pressure

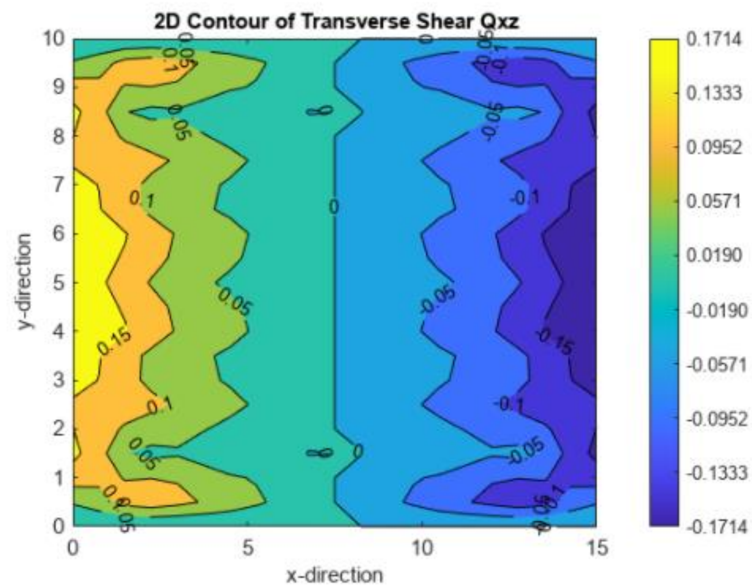




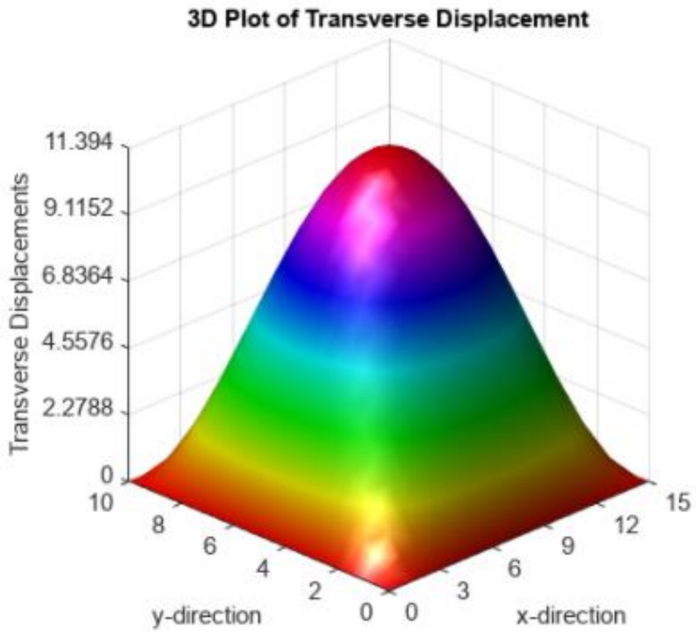
Laminate $[\pm 45]_T$: Bending under Uniform Pressure

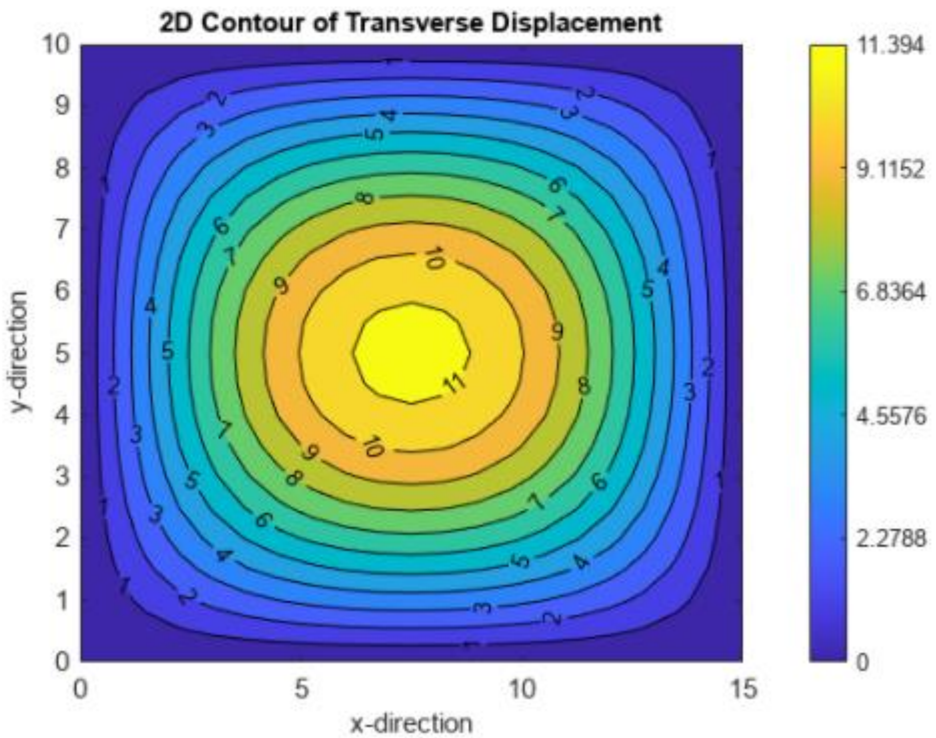




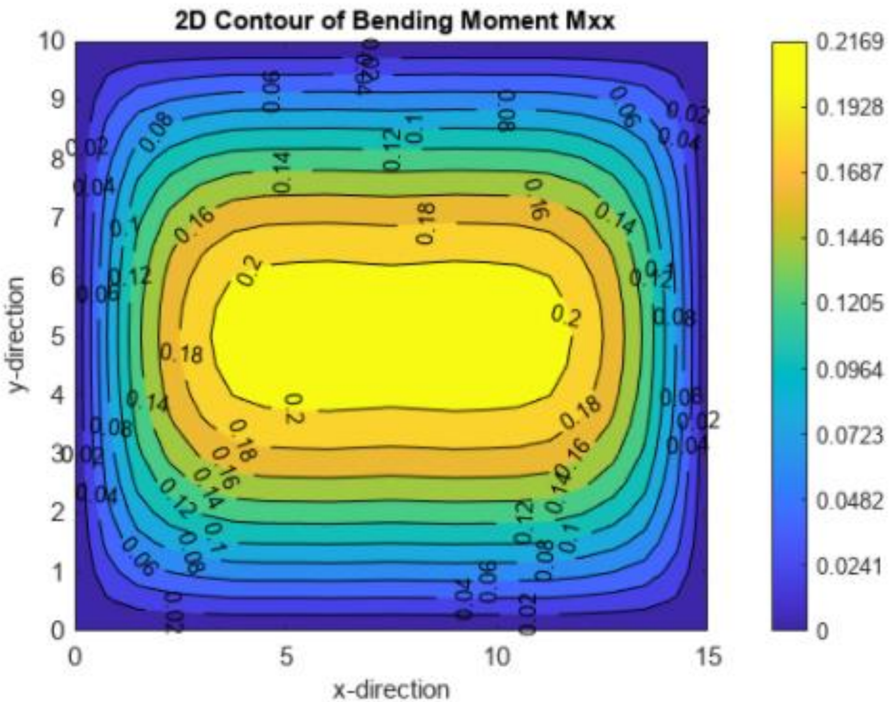


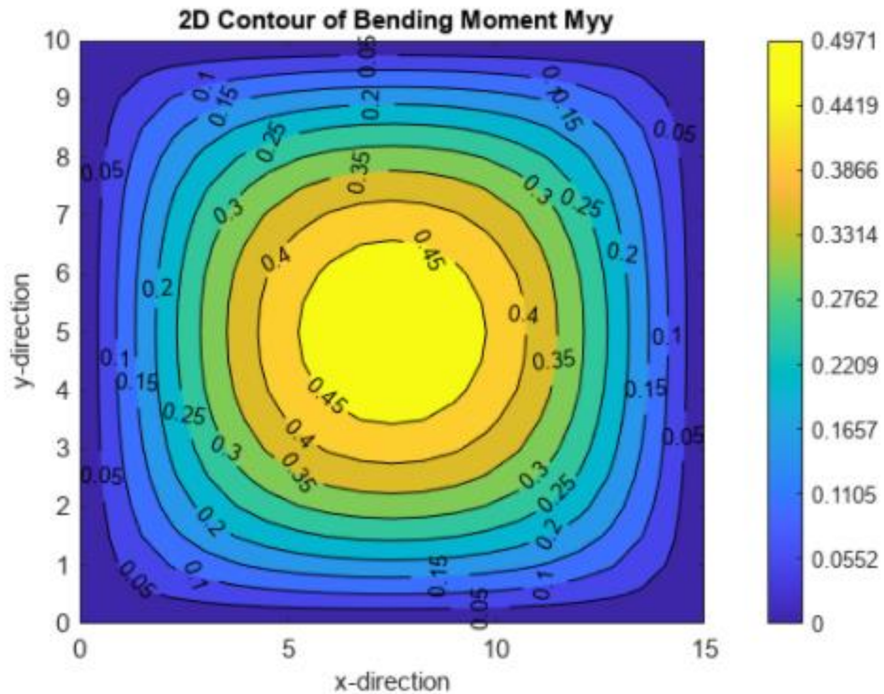
Laminate $[0/90]_T$: Bending under Uniform Pressure





Laminate $[0/90]_T$: Bending under Uniform Pressure





Laminate $[0/90]_T$: Bending under Uniform Pressure