Workshop – Composite Coupon – Phase D – Ply Shape and Ply Number Optimization

AN MSC NASTRAN SOL 200 TUTORIAL

Questions? Email: christian@ the-engineering-lab.com

Composite Workshop

This workshop is phase D of a 5-phase workshop.

Phase A

Workshop – Composite Coupon – Phase A – Determination of the optimal 0° direction of a composite

- Perform an optimization on the angle of ply 1 to maximize stiffness
- Tools Used: MSC Nastran and SOL 200 Web App

Phase B

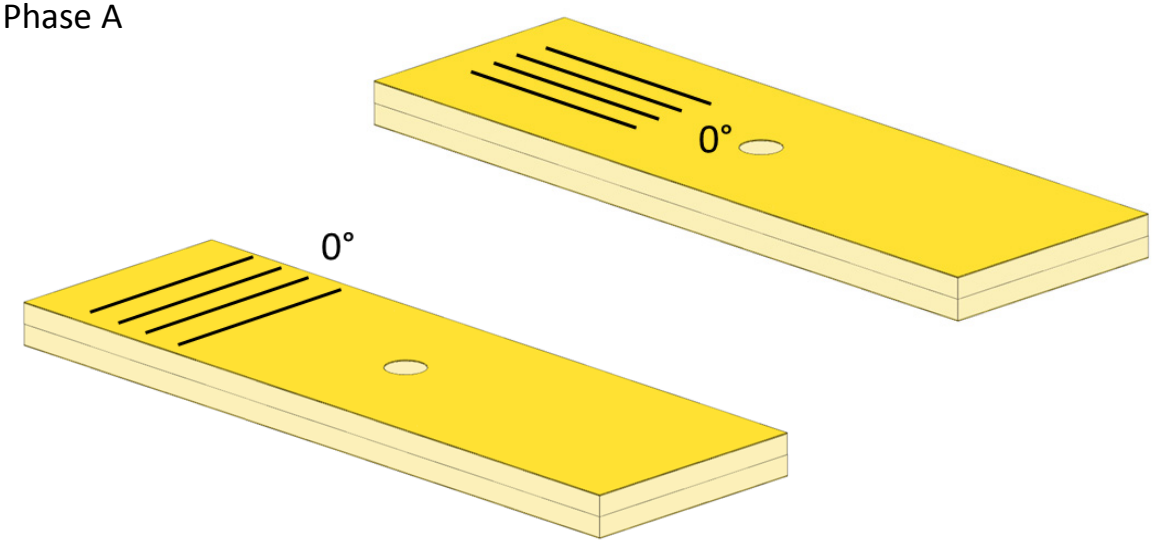
Workshop – Composite Coupon – Phase B – Baseline Ply Number Optimization

- Perform a ply number optimization with full and continuous ply shapes
- Tools Used: SOL 200 Web App (Viewer and Optimization web apps) and MSC Nastran

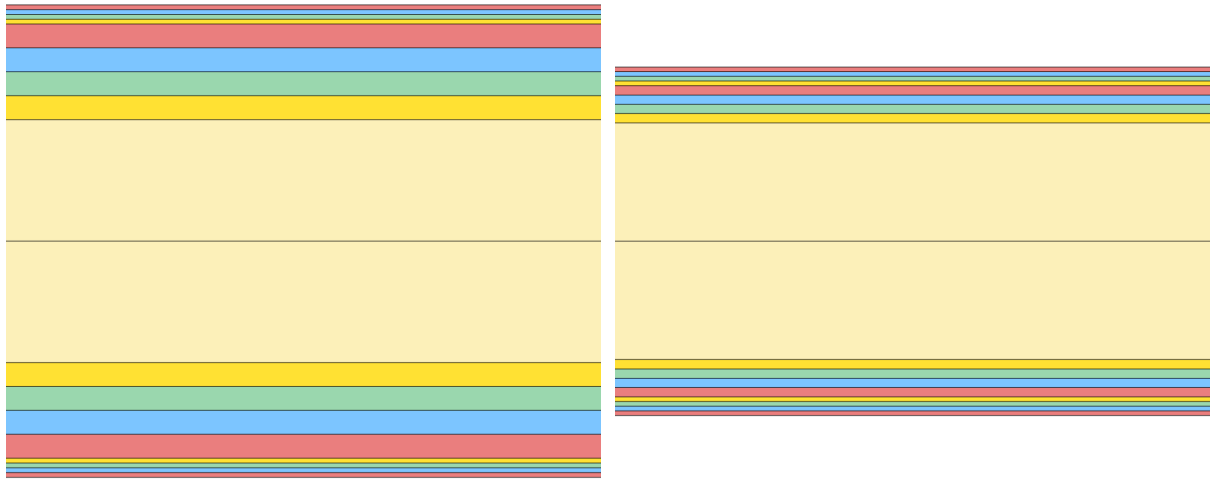
Composite Workshop

This workshop is phase D of a 5-phase workshop.

Phase A



Phase B



0° Direction Optimization

Baseline Ply Number Optimization

Composite Workshop

This workshop is phase D of a 5-phase workshop.

Phase C

Workshop – Composite Coupon – Phase C – Data Preparation for Ply Shape Optimization

- Manually create PLY000i Files
- Tools Used: Patran, MSC Nastran and SOL 200 Web App

Phase D

Workshop – Composite Coupon – Phase D – Ply Shape and Ply Number Optimization

- Input BDF and PLY000i Files
- Create Ply Shapes
- Perform Ply Number Optimization
- Inspect Plies
- Tools Used: SOL 200 Web App (Viewer and Optimization web apps) and MSC Nastran

Phase E

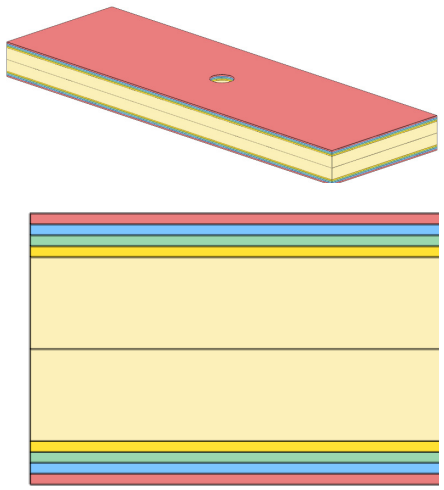
Workshop – Composite Coupon – Phase E – Stacking Sequence Optimization

- Input BDF
- Perform Stacking Sequence Optimization
- Validate Performance
- Inspect Plies
- Tools Used: SOL 200 Web App (Stacking Sequence and Viewer web apps) and MSC Nastran

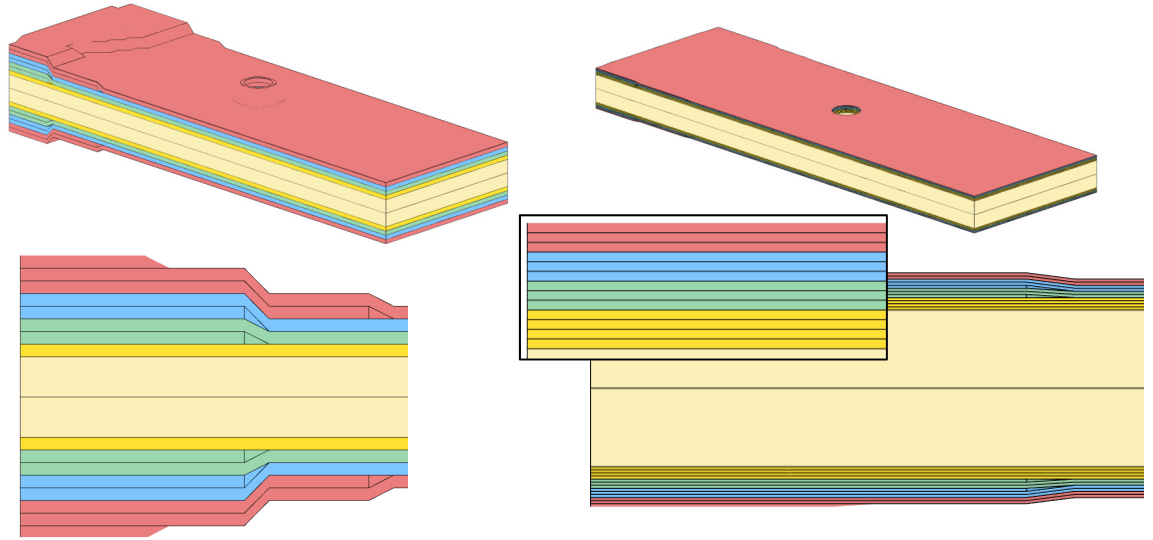
Composite Workshop

This workshop is phase D of a 5-phase workshop.

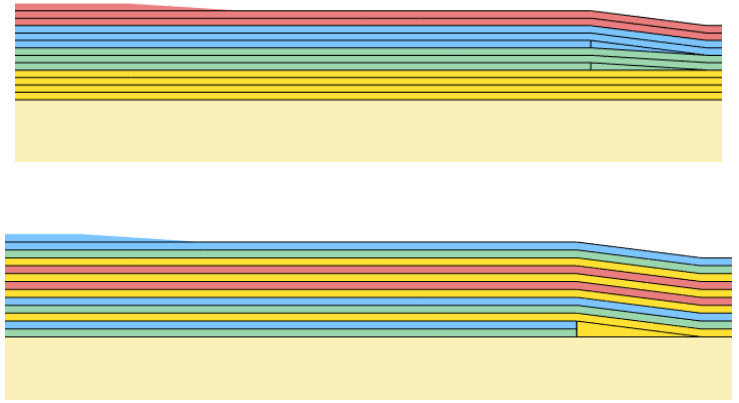
Phase C



Phase D



Phase E



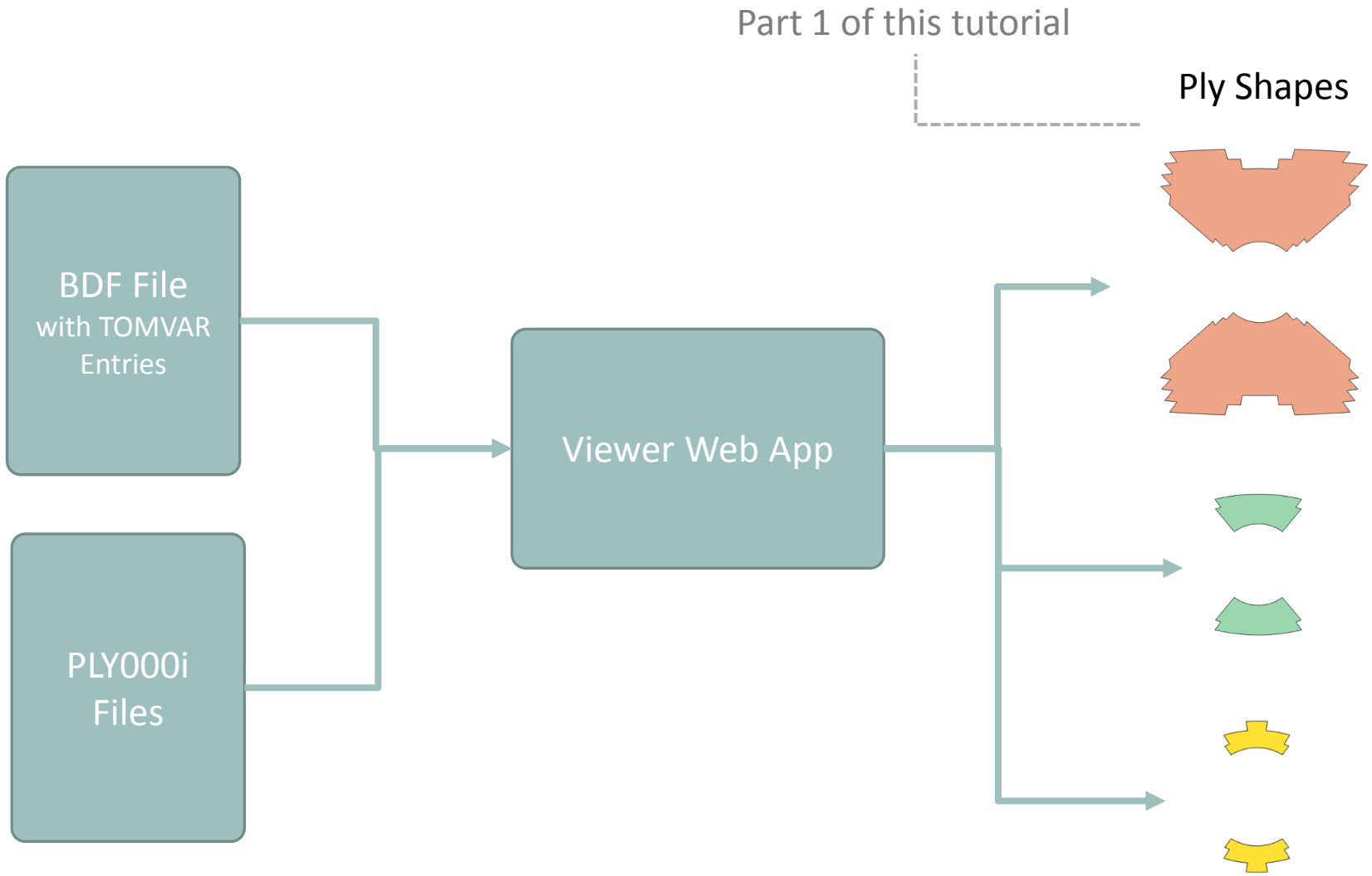
Ply Shape Optimization

Ply Number Optimization

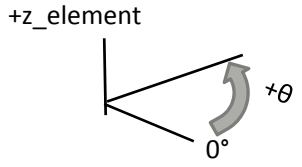
Stacking Sequence Optimization

Goal: Construct Optimal Ply Shapes and Perform Ply Number Optimization

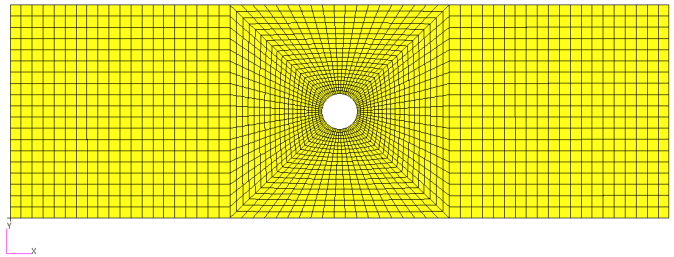
- The goal is to construct ply shapes that produce a lightweight composite but satisfy failure index constraints.
- This tutorial discusses how to operate the Viewer web app to construct new optimized ply shapes and perform a ply number optimization.



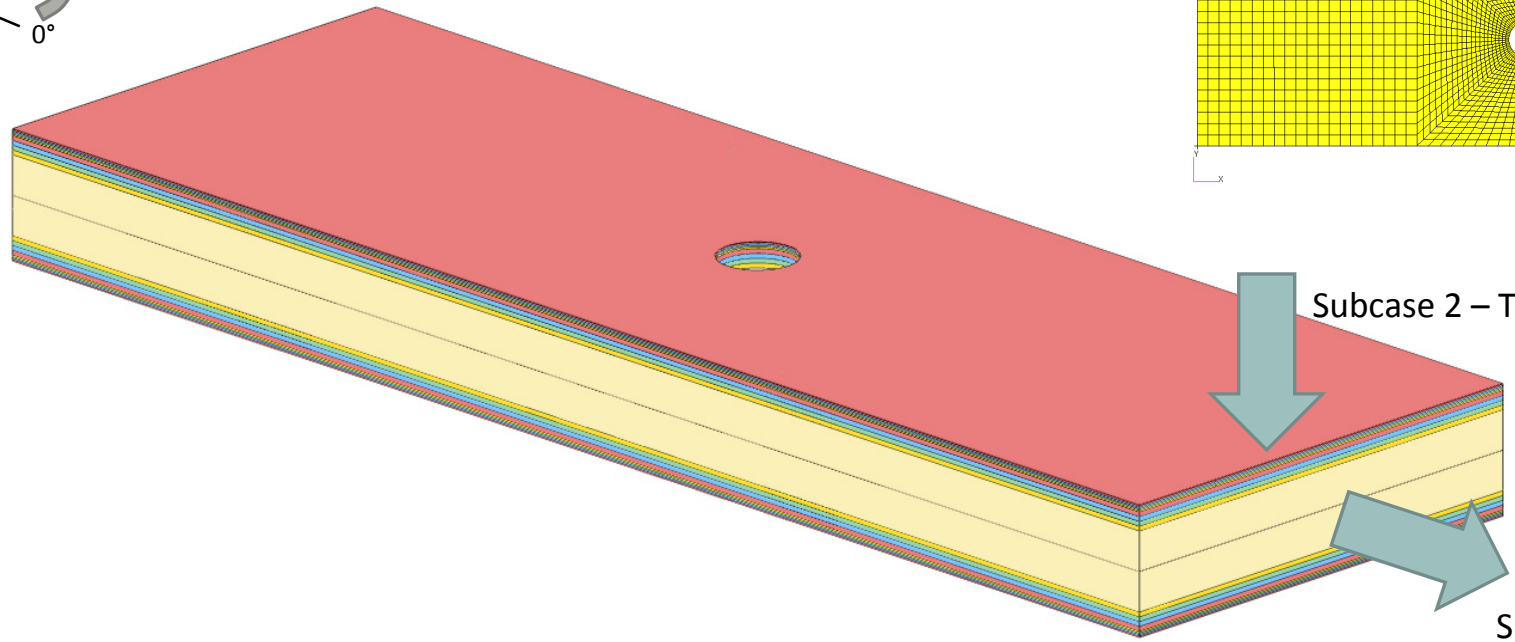
Details of the structural model



118mm x 38.1mm
Radius: 3.175mm



Edge is Clamped



Subcase 2 – Transverse Load

Subcase 1 - Tension

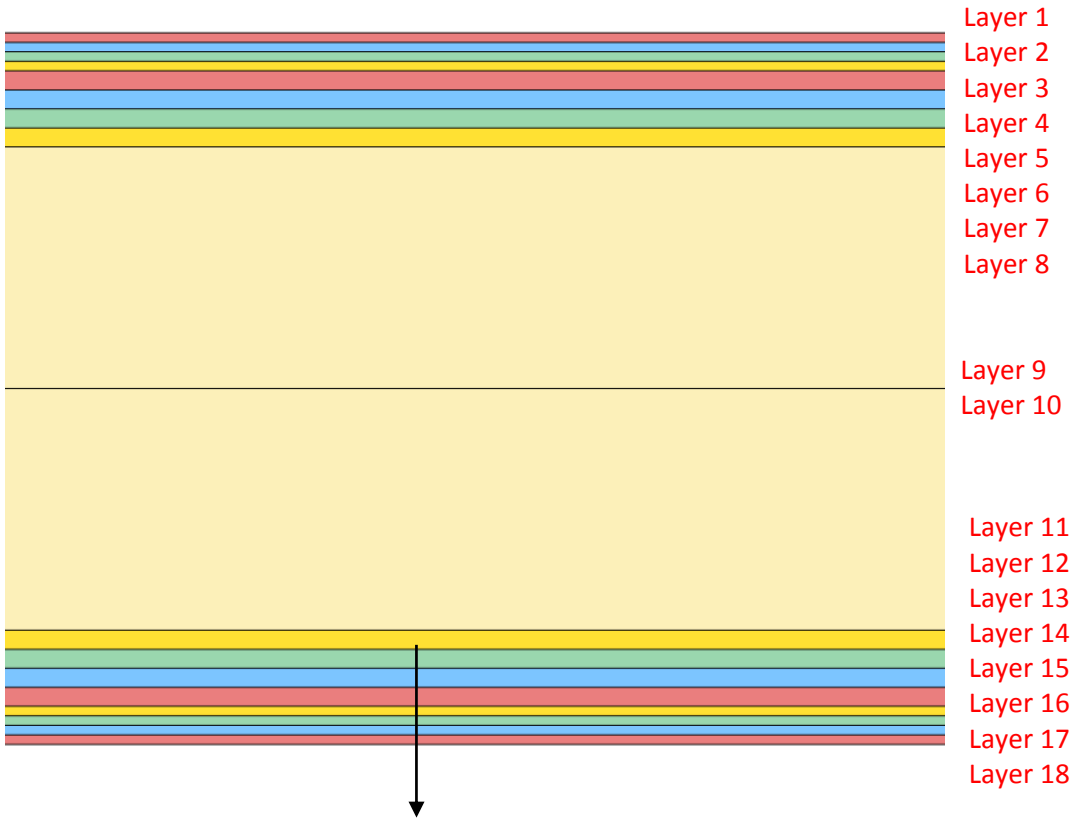
$[90/+45/-45/0/90/+45/-45/0/\ 0_{core}]_s$

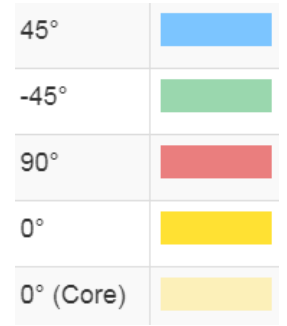
Details of the Composite Layers

This composite consists of 18 layers.

The PCOMP entry defines only 9 layers, but the LAM=SYM option indicates that the composite is symmetric. Internally, layers 10, 11, …, 18 are generated and stored.

- Layers 9 and 10 correspond to the core.
- These layers are NOT optimized.
  - Layers 1 and 18 correspond to 90° layers.
  - Layers 2 and 17 correspond to 45° layers.
  - Layers 3 and 16 correspond to -45° layers.
  - Layers 4 and 15 correspond 0° layers.
- These layers are optimized.
  - Layers 5 and 14 correspond to 90 ° layers.
  - Layers 6 and 13 correspond to 45° layers.
  - Layers 7 and 12 correspond to -45° layers.
  - Layers 8 and 11 correspond 0° layers.






```
PCOMP     1                              90.      HILL                    SYM
          101       .125       90.       YES Layer 1
          101       .125       45.       YES Layer 2
          101       .125      -45.       YES Layer 3
          101       .125        0.       YES Layer 4
          101       .25        90.       YES Layer 5
          101       .25        45.       YES Layer 6
          101       .25        -45.      YES Layer 7
          101       .25        0.        YES Layer 8
          501      3.175       0.        YES Layer 9
```

Recommended PCOMP Sequence for Optimization

When following the optimization procedure documented in this tutorial, the initial PCOMP entry should meet the following 2 criteria.

1. Include fixed and non-fixed layers

It is recommended that the PCOMP entry is formatted with fixed and non-fixed layers.

- The fixed layers will remain unchanged during the optimization procedure and their thicknesses are equal to the ply thickness. These layers are meant to track quantities such as ply stress, ply strain, failure index or strength ratio.
- The non-fixed layer's thicknesses will vary throughout the optimization procedure.

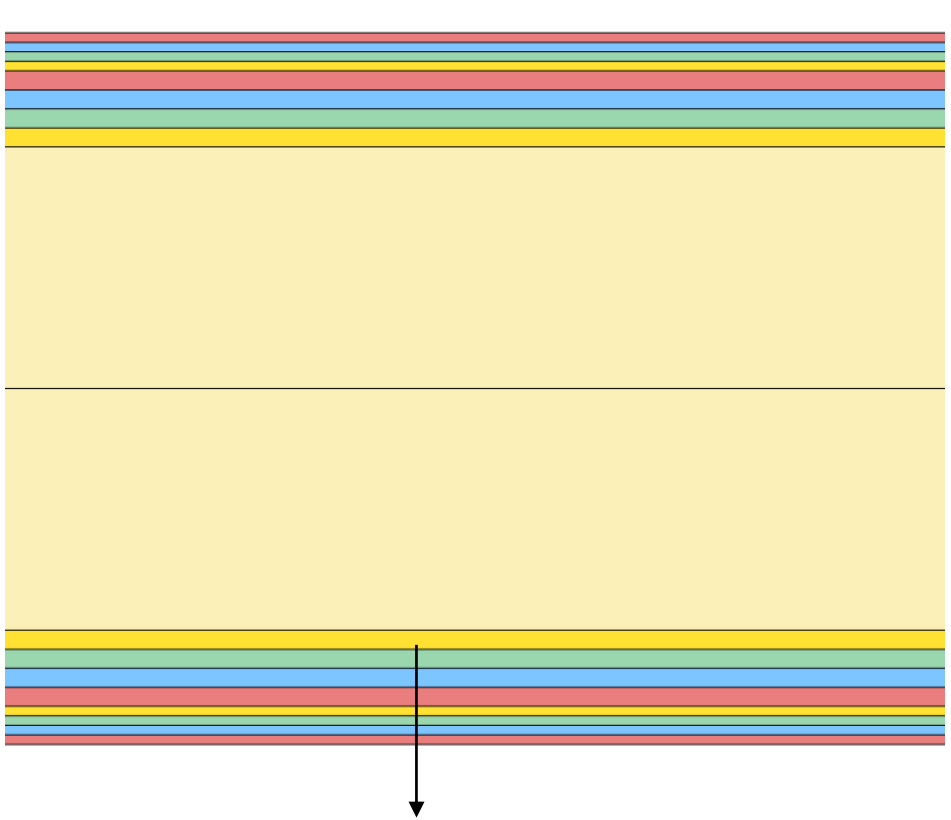
Consider the 90-degree layers. One 90-degree layer is placed as layers 1 and 5. Layer 1's thickness is fixed to .125mm. Layer 5's thickness will vary during the optimization procedure.

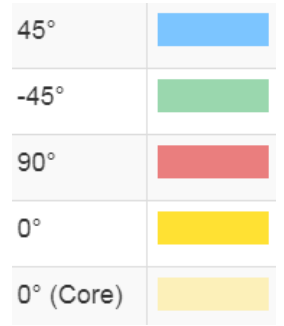
2. The sequence should have 90°, then 0° layers

The 90-degree layers should come before the 0-degree layers.

NOT OK: $[0/+45/-45/90/0/+45/-45/90/\ 0_{core}]_s$

OK: $[90/+45/-45/0/90/+45/-45/0/\ 0_{core}]_s$






```
PCOMP     1                              90.      HILL                    SYM
          101       .125       90.       YES Layer 1
          101       .125       45.       YES Layer 2
          101       .125      -45.       YES Layer 3
          101       .125        0.       YES Layer 4
          101       .25        90.       YES Layer 5
          101       .25        45.       YES Layer 6
          101       .25       -45.       YES Layer 7
          101       .25         0.       YES Layer 8
          501      3.175        0.       YES Layer 9
```

These plies remain fixed throughout the entire optimization procedure.

Create TOMVAR entries for the layers and perform ply shape and ply number optimization for these layers only

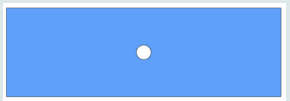
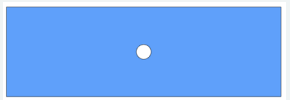
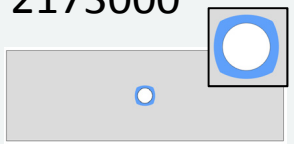
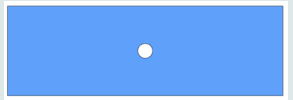
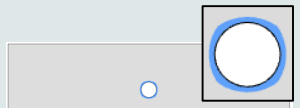
Monitor the failure index of each layer or constrain the failure index with DRESP1/DCONSTR entries.

Using PLY000i Files to Create Optimal Ply Shapes

- The data contained in PLY000i files, e.g. model.ply0005, are critical to construct optimal ply shapes. BDF and PLY000i files are used in this tutorial to construct new optimal ply shapes.
- The SOL 200 Web App's Viewer is used to create new ply shapes.
- Ply shape candidates 1, 2 and 3 are used for the 90°, ±45° and 0° layers. Additional ply shapes can yield further mass reduction. For 0°, additional ply shape candidates 4 and 5 are created.

- Each ply shape candidate is assigned a unique GPLY ID, e.g. 111000, 2111000. For more details on the GPLY ID numbering convention, refer to the appendix, section *GPLY ID Numbering Convention (sPLC00).*
- Ply shapes are created based on the data contained in the PLY000 files. The PLY000i files are generated by Topometry Optimization or may be created manually, as done in this tutorial. Alternatively, both methods may be combined for a hybrid method.
- Some GPLY IDs have a number 2 as a suffix. This composite is symmetric and the suffix of 2 indicates a symmetric ply. For example, GPLY ID 151000 has a corresponding 2151000 mirror ply.

Ply Shape

Layer, Theta	Ply Shape Candidate 1	Ply Shape Candidate 2	Ply Shape Candidate 3	Ply Shape Candidate 4	Ply Shape Candidate 5
5 90°	151000, 2151000 	152000, 2152000 	153000, 2153000 		
6, 7 ±45°	161000, 2161000 171000, 2171000 	162000, 2162000 172000, 2172000 	163000, 2163000 173000, 2173000 		
8 0°	181000, 2181000 	182000, 2182000 	183000, 2183000 	184000, 2184000 	185000, 2185000 

Optimization Problem Statement

Design Variables

y1: Number of plies for 90°, GPLY IDs: 151000, 2151000

y2: Number of plies for 90°, GPLY IDs: 152000, 2152000

y3: Number of plies for 90°, GPLY IDs: 153000, 2153000

y4: Number of plies for 45°, GPLY IDs: 161000, 171000, 2171000, 2161000

y5: Number of plies for 45°, GPLY IDs: 162000, 172000, 2172000, 2162000

y6: Number of plies for 45°, GPLY IDs: 163000, 173000, 2173000, 2163000

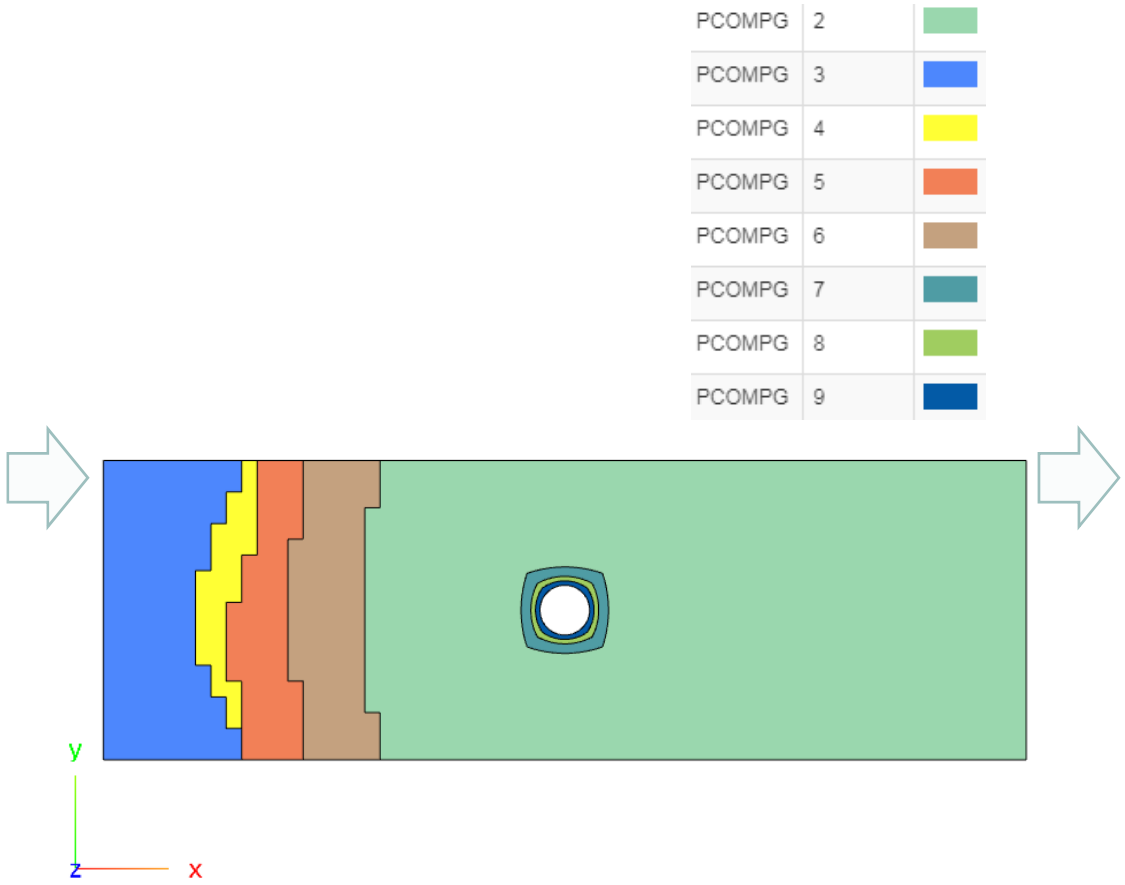
y7: Number of plies for 0°, GPLY IDs: 181000, 2181000

y8: Number of plies for 0°, GPLY IDs: 182000, 2182000

y9: Number of plies for 0°, GPLY IDs: 183000, 2183000

y10: Number of plies for 0°, GPLY IDs: 184000, 2184000

y11: Number of plies for 0°, GPLY IDs: 185000, 2185000



Design Objective

Minimize weight

Design Constraints

ri: Constrain the failure index of each ply

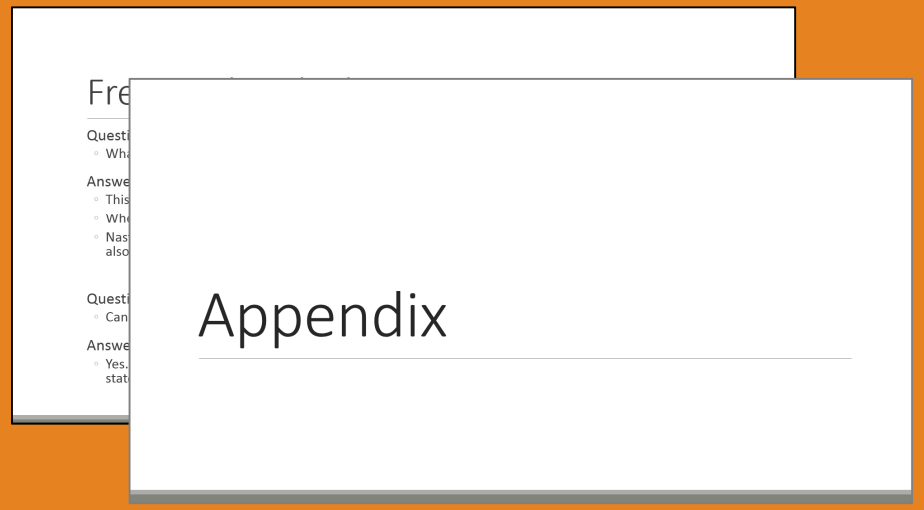
ri < .95

For i=1, 2, 3, …

More Information Available in the Appendix

The Appendix includes information regarding the following:

- What filter values to use?
- PCOMPG Zones
- Options for Ply Number Optimization
- GPLY ID Numbering Convention (sPLC000)
- Optimizing Composite Ply Shapes and Numbers for Uniaxial Loading
- Optimizing Composite Ply Shapes and Numbers for Bending



Contact me

- Nastran SOL 200 training
- Nastran SOL 200 questions
- Structural or mechanical optimization questions
- Access to the SOL 200 Web App

christian@ the-engineering-lab.com

Tutorial

Tutorial Overview

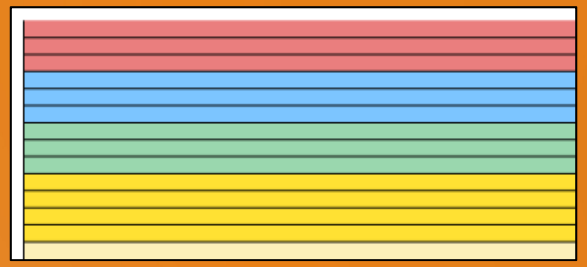
1. Part 1 – Ply Shape Creation
2. Part 2 – Ply Number Optimization
3. Part 3 – View New Plies

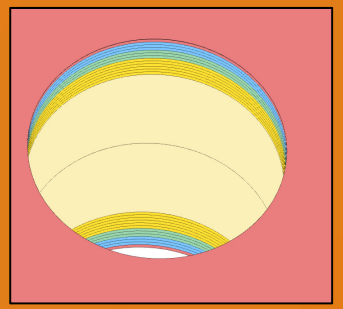
Special Topics Covered

Ply Shape Editing - Ply shapes require the creation of multiple PCOMP/PCOMPG entries and assigning these entries to different 2D elements, e.g. CQUAD4, CTRIA3. This tutorial describes this procedure via the use of the SOL 200 Web App. Ultimately, optimal ply shapes are created.

Ply Number Optimization – Once the optimal ply shapes are constructed, a ply number optimization is performed.

Ply Thickness Inspection - The final plies may be visually inspected via the use of the Viewer web app.





SOL 200 Web App Capabilities

The Post-processor Web App and HDF5 Explorer are free to MSC Nastran users.

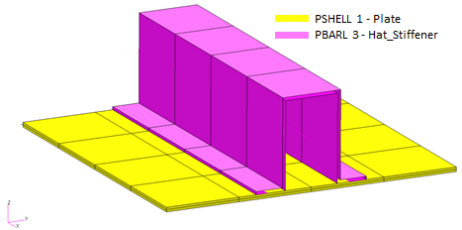
Compatibility

- Google Chrome, Mozilla Firefox or Microsoft Edge
- Windows and Red Hat Linux
- Installable on a company laptop, workstation or server. All data remains within your company.

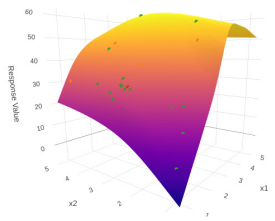
Benefits

- REAL TIME error detection. 200+ error validations.
- REALT TIME creation of bulk data entries.
- Web browser accessible
- Free Post-processor web apps
- +80 tutorials

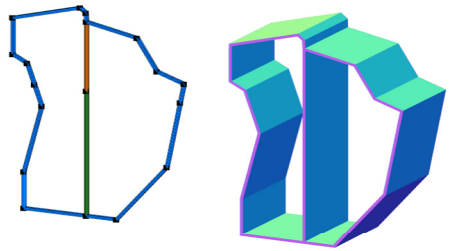
Web Apps



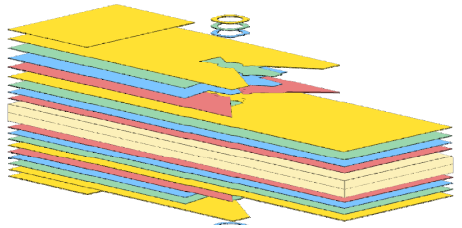
Web Apps for MSC Nastran SOL 200
Pre/post for MSC Nastran SOL 200. Support for size, topology, topometry, topography, multi-model optimization.



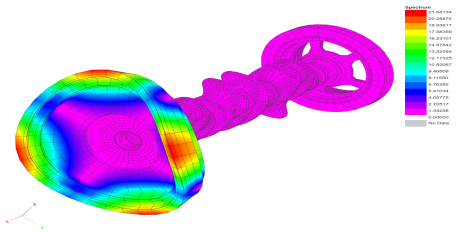
Machine Learning Web App
Bayesian Optimization for nonlinear response optimization (SOL 400)



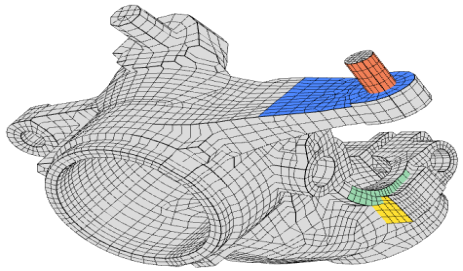
PBMSECT Web App
Generate PBMSECT and PBRSECT entries graphically



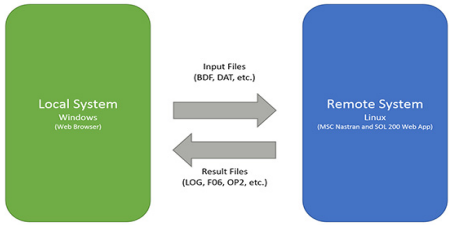
Ply Shape Optimization Web App
Optimize composite ply drop-off locations, and generate new PCOMPG entries



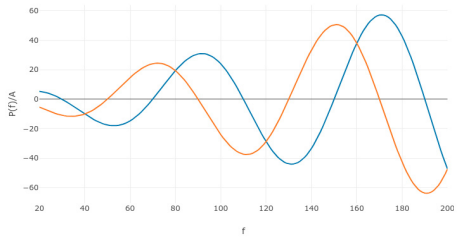
Post-processor Web App
View MSC Nastran results in a web browser on Windows and Linux



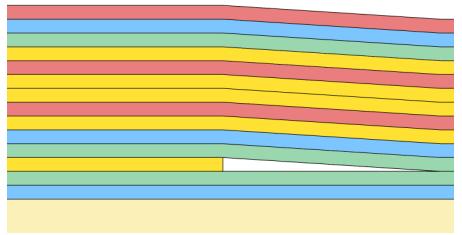
Shape Optimization Web App
Use a web application to configure and perform shape optimization.



Remote Execution Web App
Run MSC Nastran jobs on remote Linux or Windows systems available on the local network



Dynamic Loads Web App
Generate RLOAD1, RLOAD2 and DLOAD entries graphically



Stacking Sequence Web App
Optimize the stacking sequence of composite laminate plies

HDF5 Explorer Web App
Create graphs (XY plots) using data from the H5 file

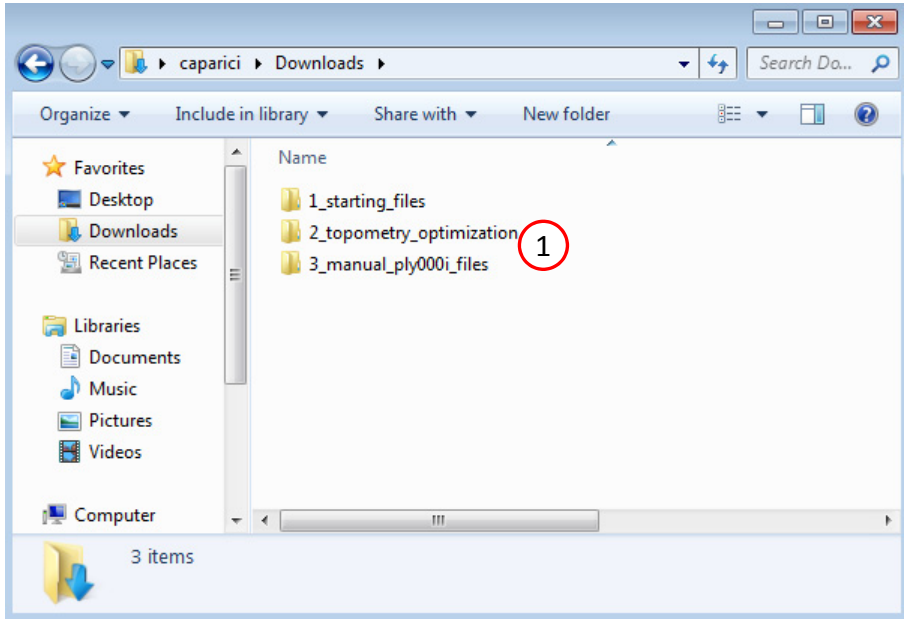
Part 1 – Ply Shape Creation

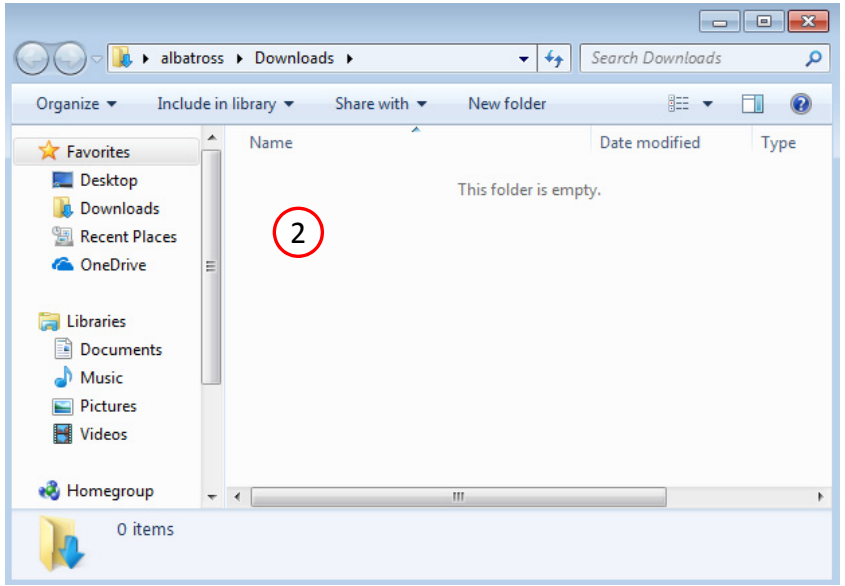
Before Starting

This tutorial is a continuation of the previous tutorial. You have two starting options.

1. You may continue on from the previous tutorial with the same BDF files.
2. Or you may start with prepared BDF files available in the User's Guide. Ensure the Downloads directory is empty in order to prevent confusion with other files. The next slides detail how to download prepared BDF files from the User's Guide.

- Throughout this workshop, you will be working with multiple file types and directories such as:
  - .bdf/.dat
  - nastran_working_directory
  - .f06, .log, .pch, .h5, etc.
- To minimize confusion with files and folders, it is encouraged to start with a clean directory.





Go to the User's Guide

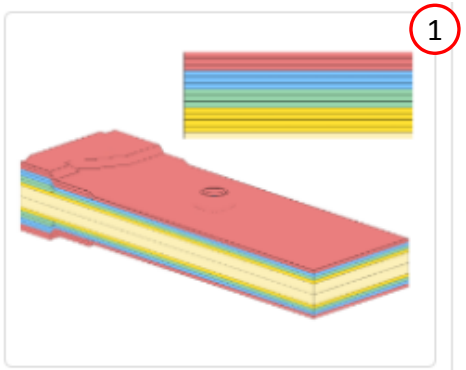
1. Click on the indicated link

- The necessary BDF files for this tutorial are available in the Tutorials section of the User's Guide.

Obtain Starting Files

1. Find the indicated example
2. Click Link
3. The starting file has been downloaded

- When starting the procedure, all the necessary BDF files must be collected together.



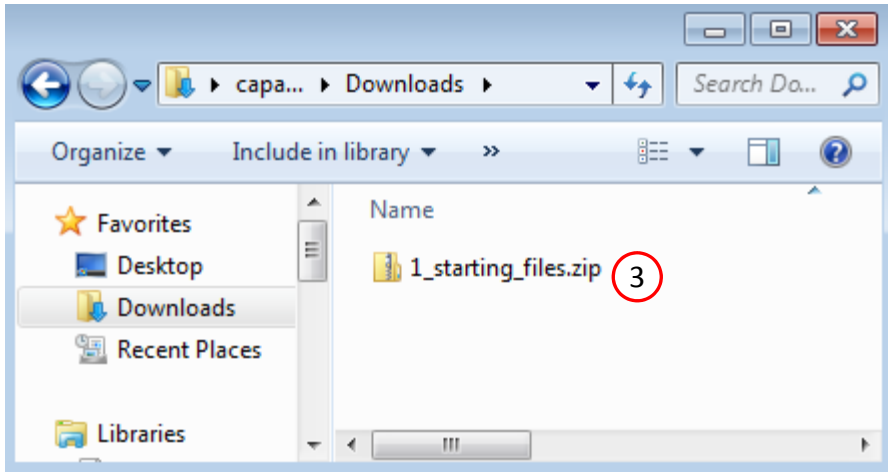
1

Composite Coupon – Phase D – Ply Shape and Ply Number Optimization

This tutorial details the process to build optimal ply shapes and perform a ply number optimization. The optimal ply shapes are constructed to follow the contours of the failure indices. The ply number optimization involves minimizing weight and constraining the failure indices of plies. The PLY000i files and BDF files from the previous tutorial, phase C, are used in this tutorial.

This is the fourth phase in a 5-phase tutorial series.

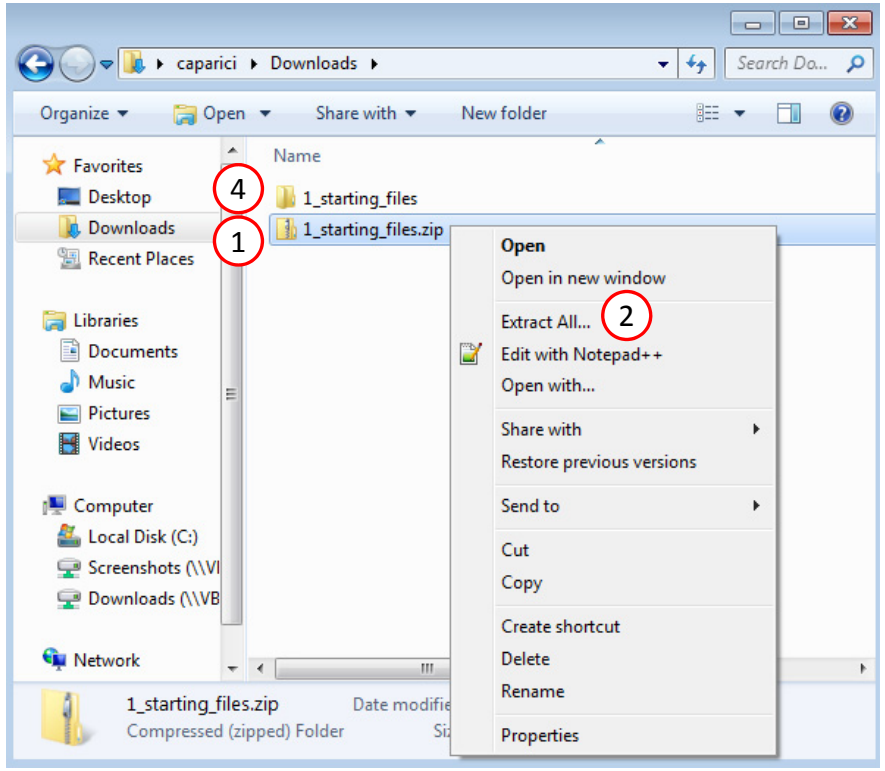
Starting BDF Files: Link 2
Solution BDF Files: Link

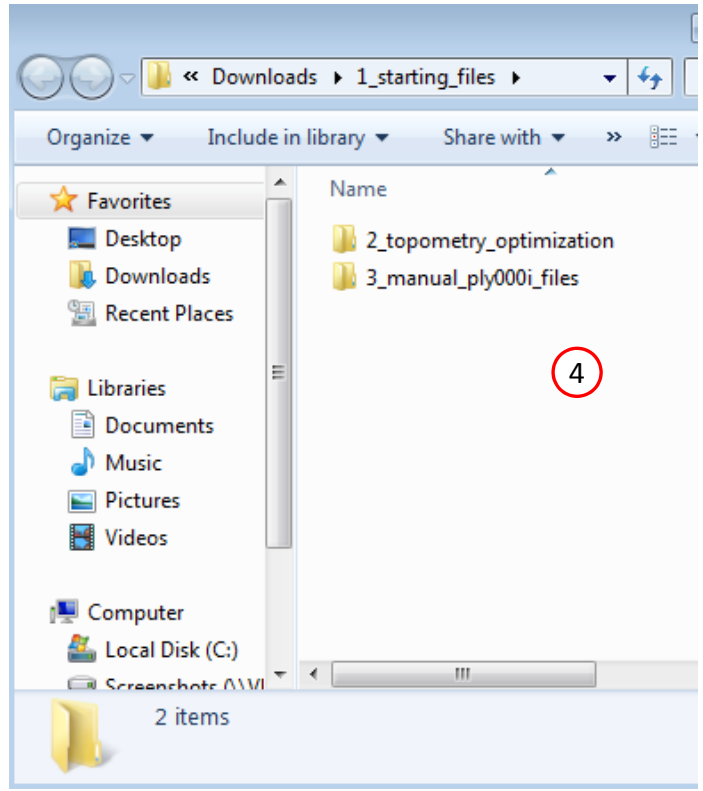


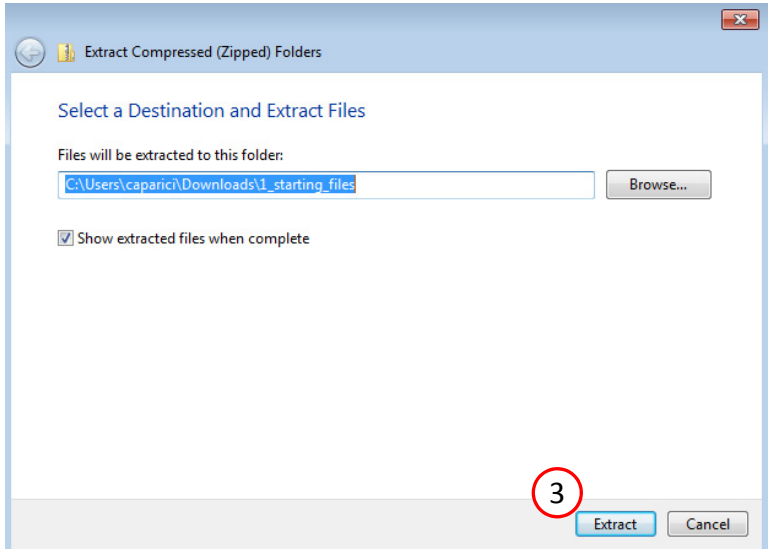
Obtain Starting Files

1. Right click on the zip file
2. Select Extract All…
3. Click Extract
4. The starting files are now available in a folder

- This example is using a previously created design model. The design model is a model that has been converted to SOL 200 and contains bulk data entries describing the optimization problem statement, e.g. variables, objective and constraints.







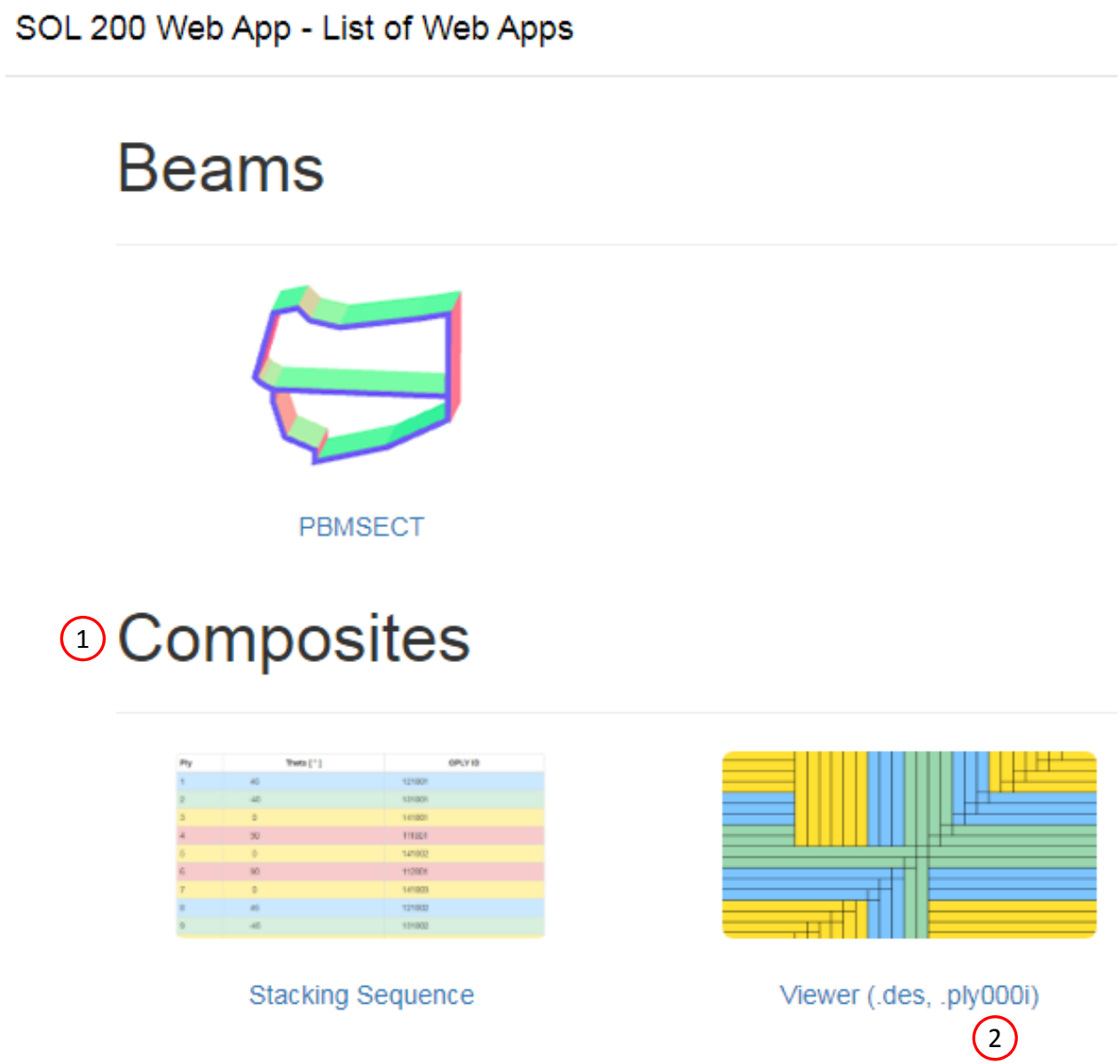
Open the Correct Page

1. Click on the indicated link

- MSC Nastran can perform many optimization types. The SOL 200 Web App includes dedicated web apps for the following:
  - Optimization for SOL 200 (Size, Topology, Topometry, Topography, Local Optimization, Sensitivity Analysis and Global Optimization)
  - Multi Model Optimization
  - Machine Learning
- The web app also features the HDF5 Explorer, a web application to extract results from the H5 file type.

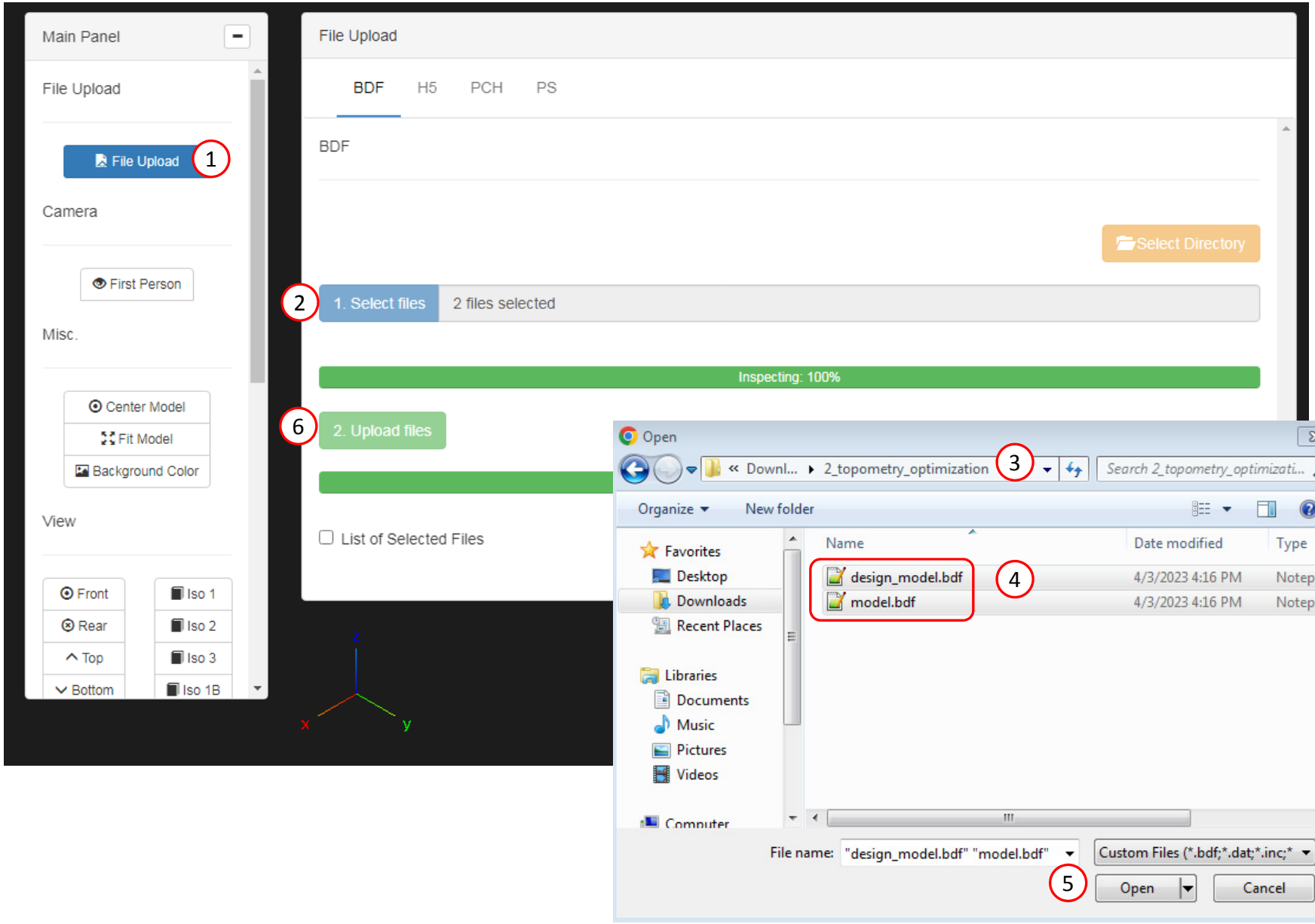
Open the Viewer

1. Navigate to the Composites section
2. Click Viewer



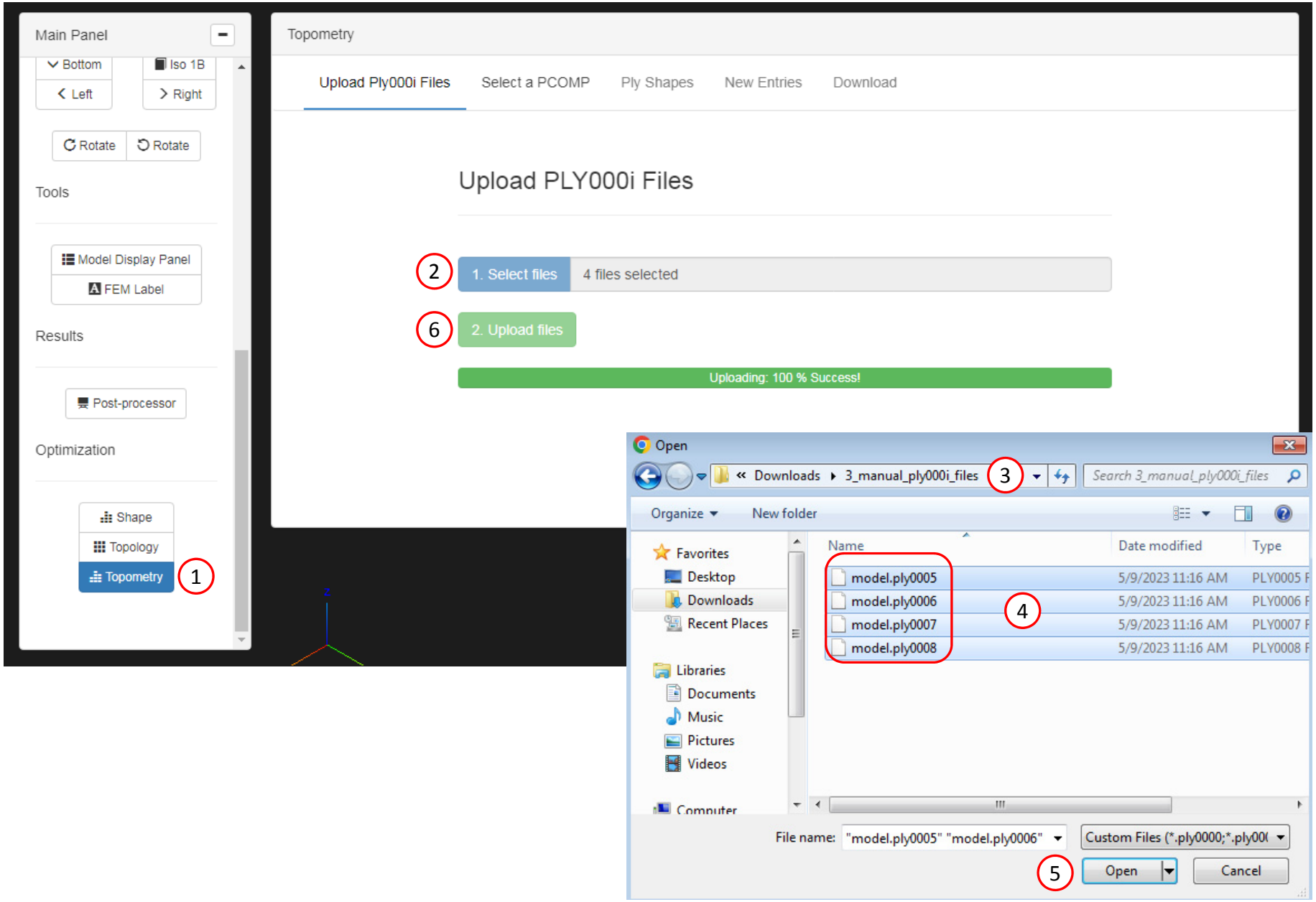
Import BDF Files

1. Click File Upload
2. Click Select files
3. Navigate to directory 2_topometry_optimization
4. Select the indicated files
5. Click Open
6. Click Upload files



Import PLY000i Files

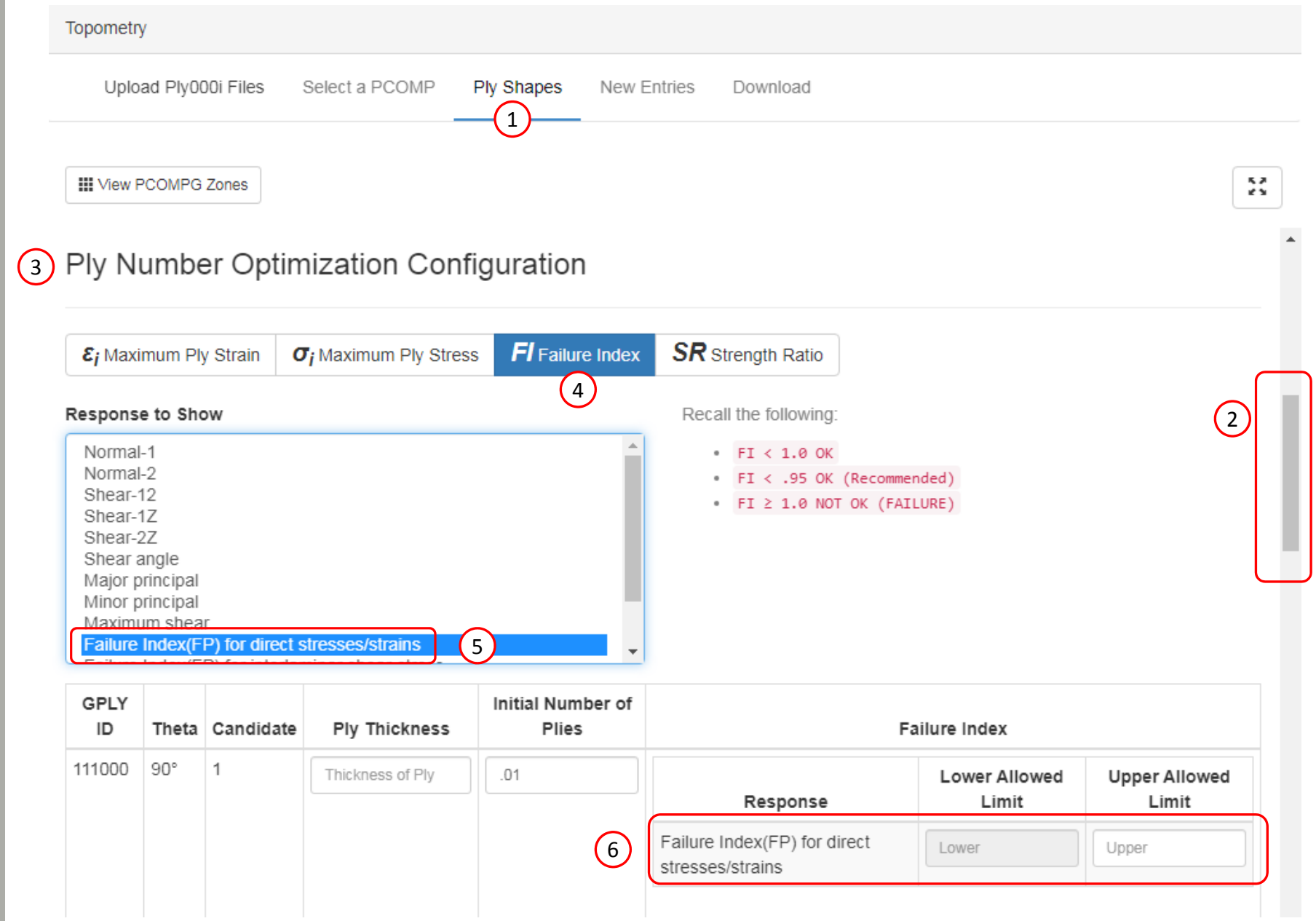
1. Click Topometry
2. Click Select files
3. Navigate to directory 3_manual_ply000i_files
4. Select the indicated files
5. Click Open
6. Click Upload files



Configure Ply Number Optimization

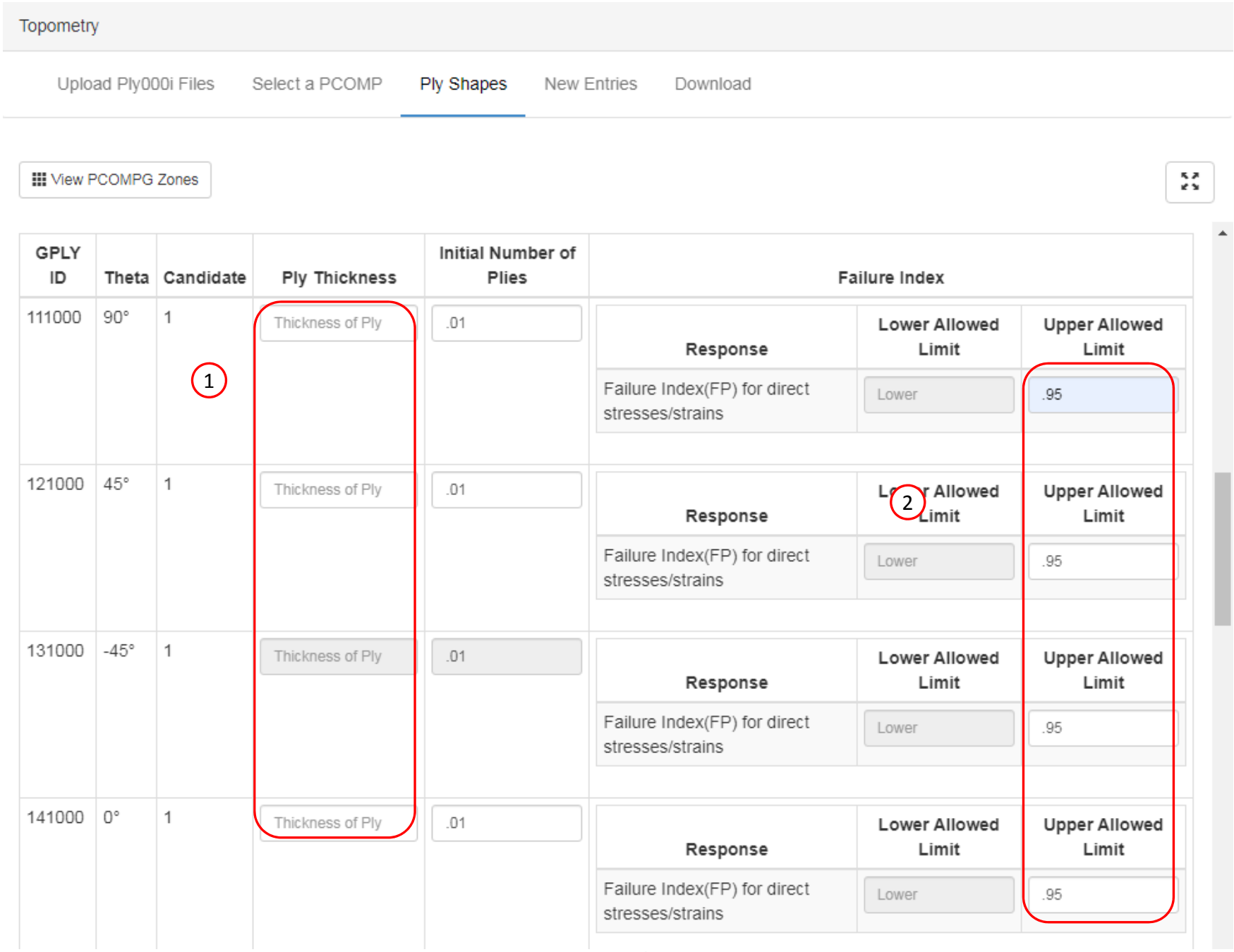
1. Click Ply Shapes
2. Use the scroll bar to navigate to different sections
3. Navigate to section Ply Number Optimization Configuration
4. Click Failure Index
5. Select only Failure Index(FP) for direct stresses/strains
6. Ensure only the following row is displayed: Failure Index(FP) for direct stresses/strain

- There are many additional responses that may be set as design constraints, including ply stresses, strains, and others.



Configure Ply Number Optimization

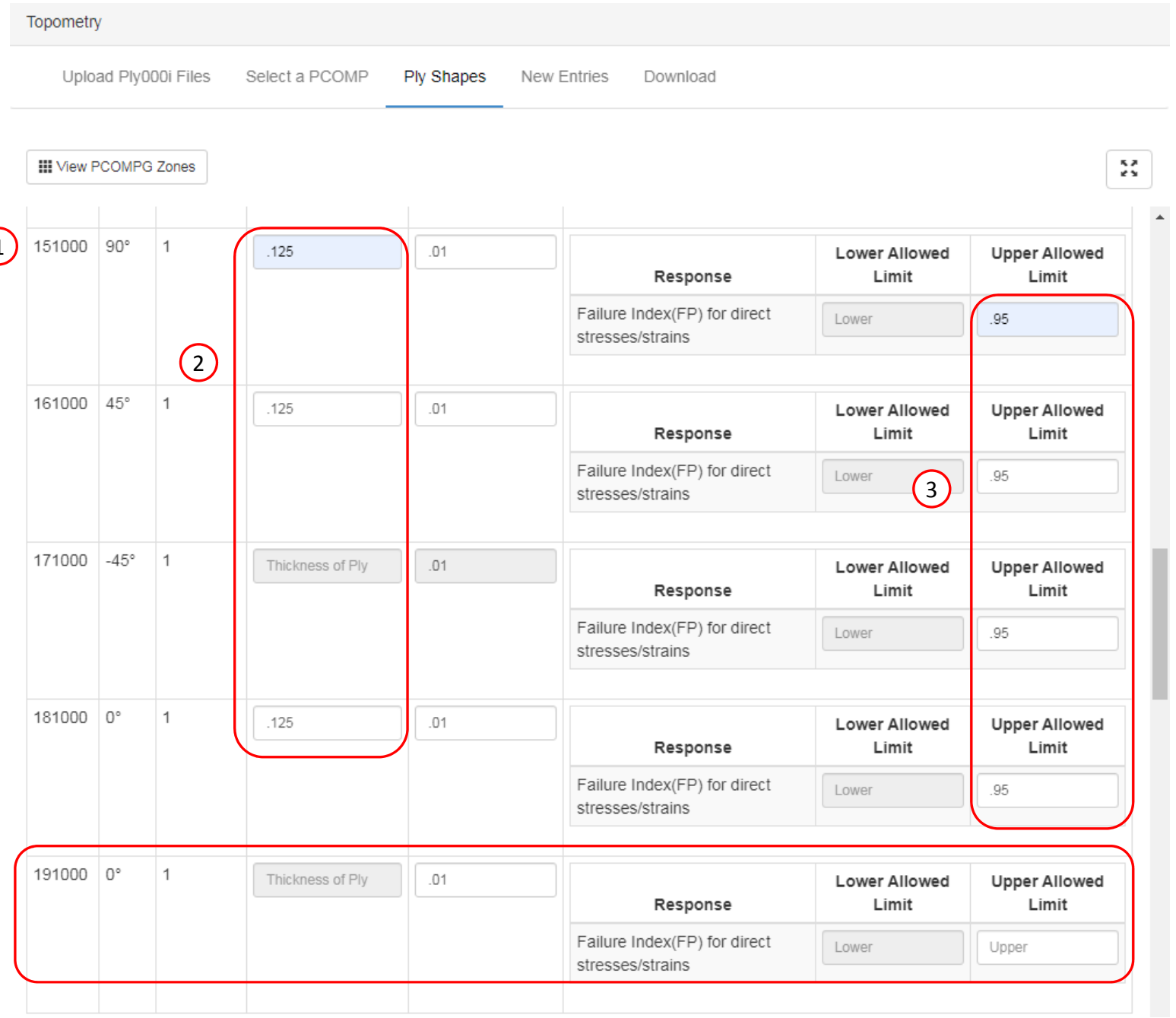
1. Do NOT set a ply thickness for the fist 4 layers.
   - The first 4 layers correspond to the outer layers and should remain fixed during the optimization. Supplying a ply thickness will set the layer as a design variable. Do NOT set a ply thickness for the first 4 layers.
2. For the first 4 layers' failure index, set the upper bound to .95



Configure Ply Number Optimization

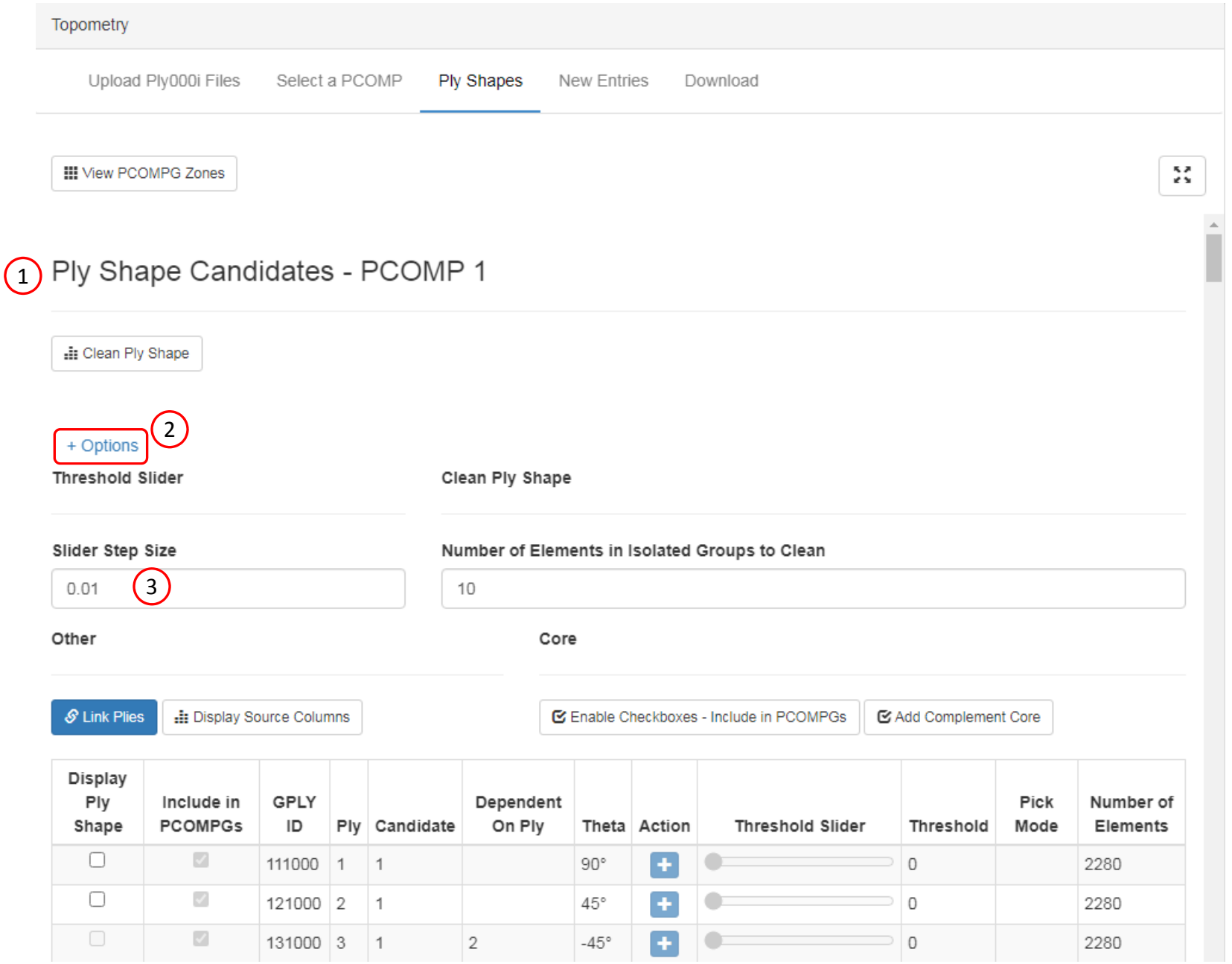
1. Scroll to the layer with GPLY ID 151000
2. For the first 4 layers, set the Ply Thickness to .125 mm
   - For GPLY ID 171000 (-45°), the ply thickness option is disabled. The -45° is dependent on the +45° layer. One ply number variable is required for both +45° and -45°.
3. For the indicated plies, set the upper bound to .95
4. The 9th layer (GPLY ID 191000) is the core. This core layer is not optimized, nor is a constraint created for the core.

- It should be noted that if desired, the thickness of the core may also be optimized as long as a TOMVAR entry is defined for the core layer and a PLY000i file is created for the core layer. For this example, if the core layer is to be optimized, TOMVAR entry for layer 9 should be created and a PLY0009 file should be available.



Create Ply Shape Candidates

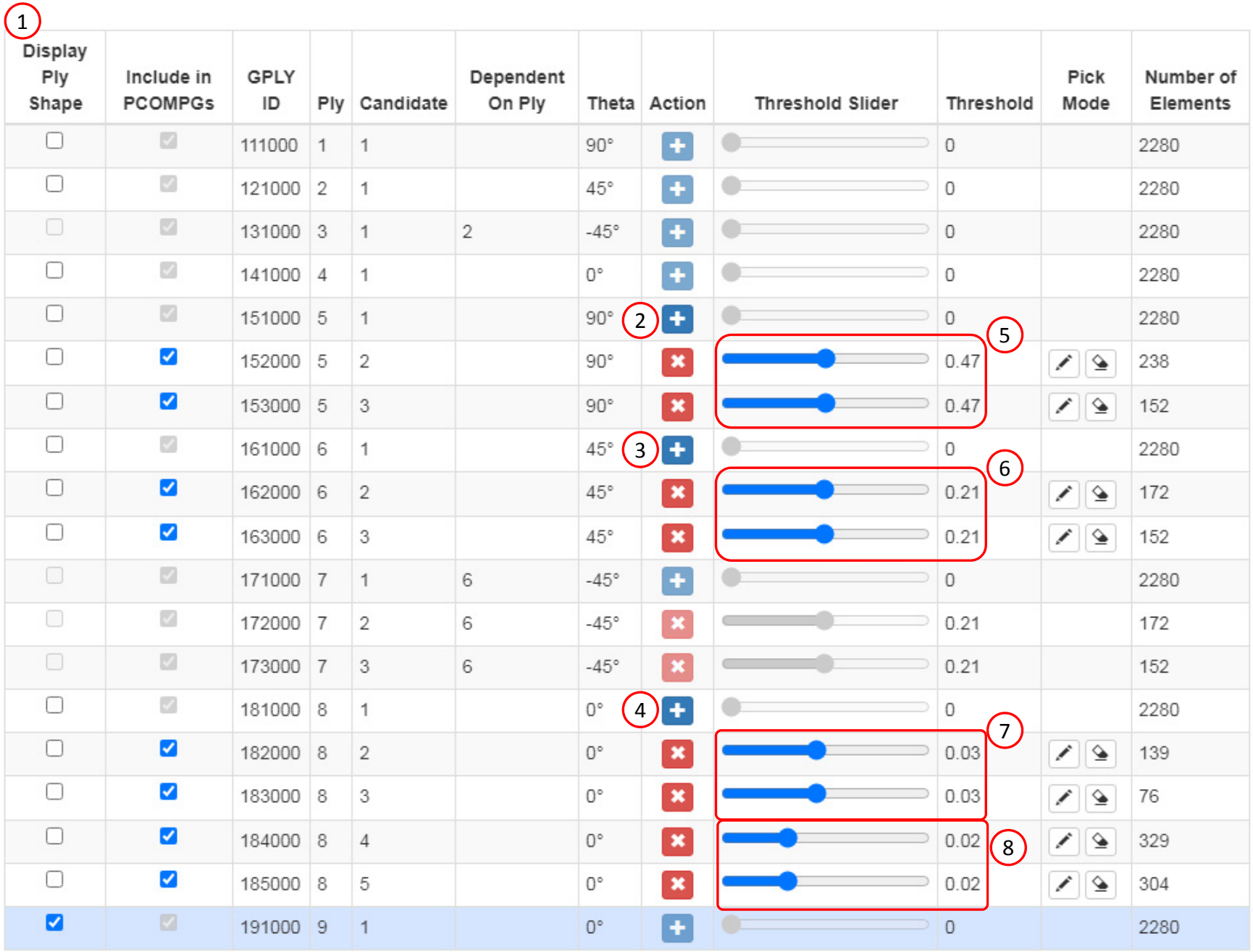
1. Navigate to section Ply Shape Candidates
2. Click +Options
3. Set the Slider Step Size to 0.01



Create Ply Shape Candidates

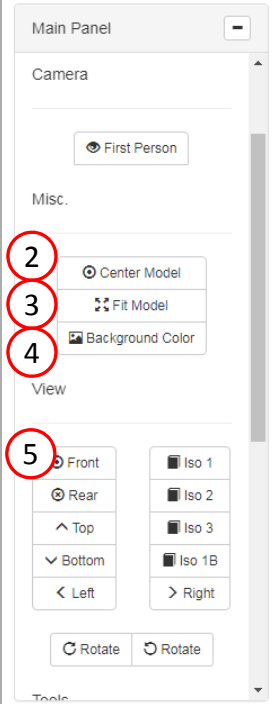
1. Scroll to the following table
2. Click the indicated plus (+) icon 2 times to create 2 ply shape candidates for the 90° layer.
3. Click the indicated plus (+) icon 2 times to create 2 ply shape candidates for the 45° layer. Since the -45° is linked to the +45° layer, two -45° are also created.
4. Click the indicated plus (+) icon 4 times to create 4 ply shape candidates for the 0° layer.
5. Move the indicated Threshold Slider to a value of 0.47
6. Move the indicated Threshold Slider to a value of 0.21
7. Move the indicated Threshold Slider to a value of 0.03
8. Move the indicated Threshold Slider to a value of 0.02

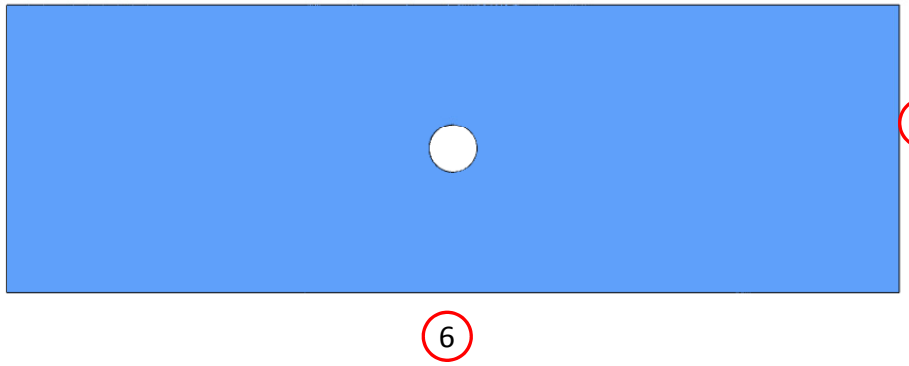
- Values of 0.47 and .21 are used. Refer to the appendix, section *What filter values to use*, for a discussion on how these values were selected.

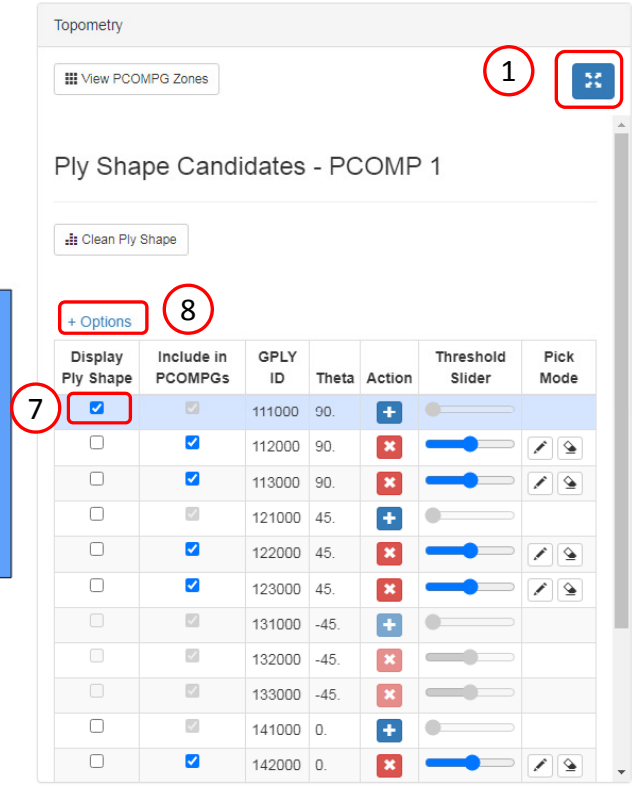


Position the Model

1. Click the indicated icon to minimize the width of the panel
2. Click Center Model
3. Click Fit Model
4. Click Background Color
5. Click Front
6. Use the mouse scroll wheel to zoom out, and press and hold the right mouse button, and drag the mouse left ward to drag the model into view.
7. Mark the indicated checkbox to display the first ply shape
8. Click +Options to hide the options section





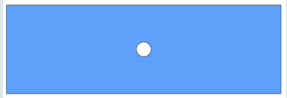
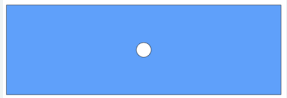
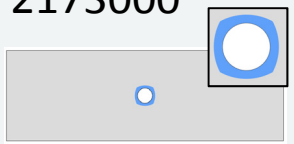
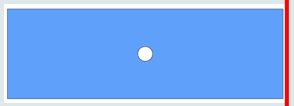


Ply Shape Candidates Creation

1. The indicated ply shape candidates will be created

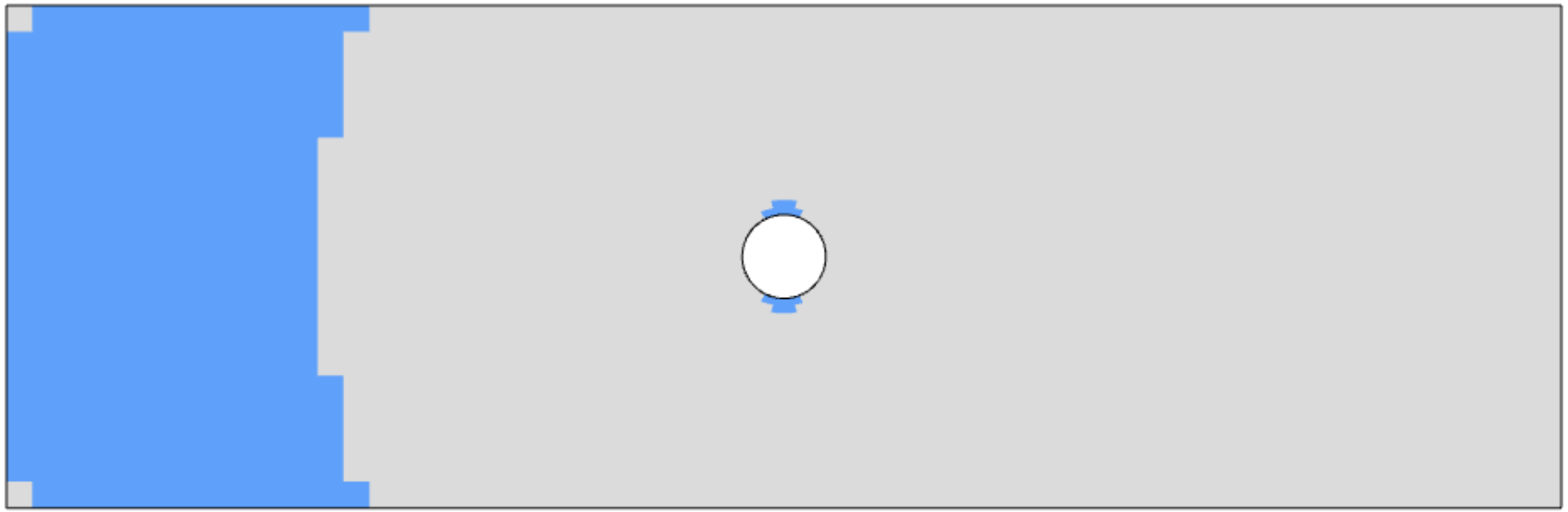
1

Ply Shape

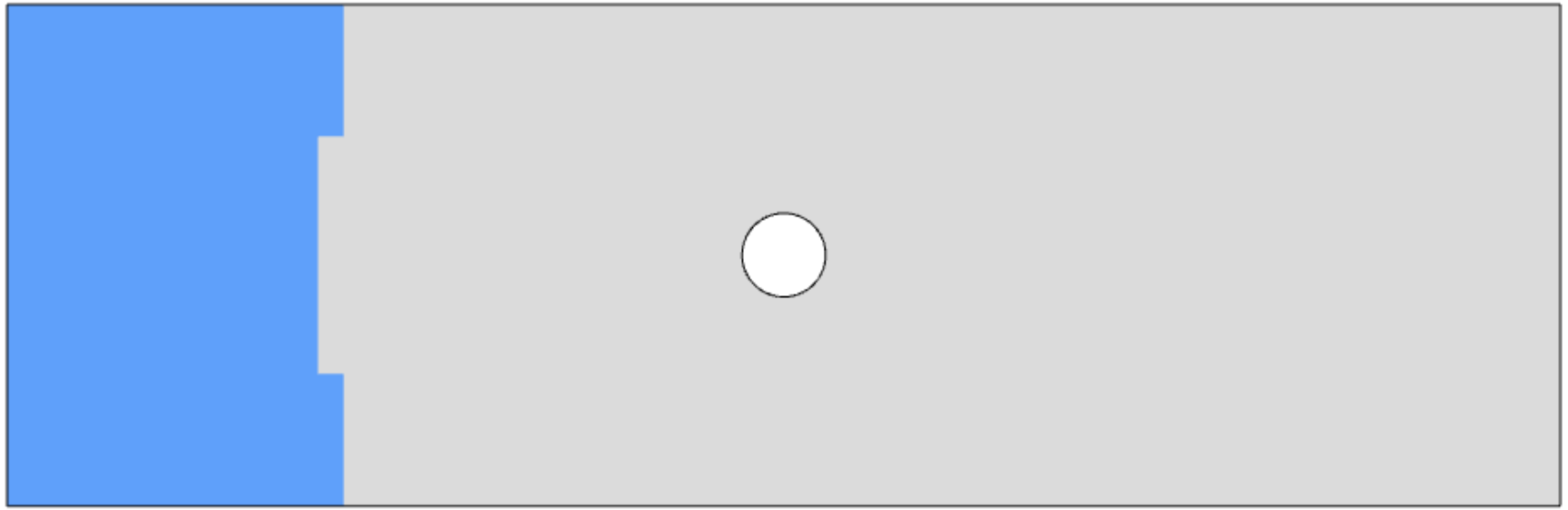
Layer, Theta	Ply Shape Candidate 1	Ply Shape Candidate 2	Ply Shape Candidate 3	Ply Shape Candidate 4	Ply Shape Candidate 5
5 90°	151000, 2151000 	152000, 2152000 	153000, 2153000 		
6, 7 ±45°	161000, 2161000 171000, 2171000 	162000, 2162000 172000, 2172000 	163000, 2163000 173000, 2173000 		
8 0°	181000, 2181000 	182000, 2182000 	183000, 2183000 	184000, 2184000 	185000, 2185000 

Ply Shape Editing: Candidate 2 for 90°

Before



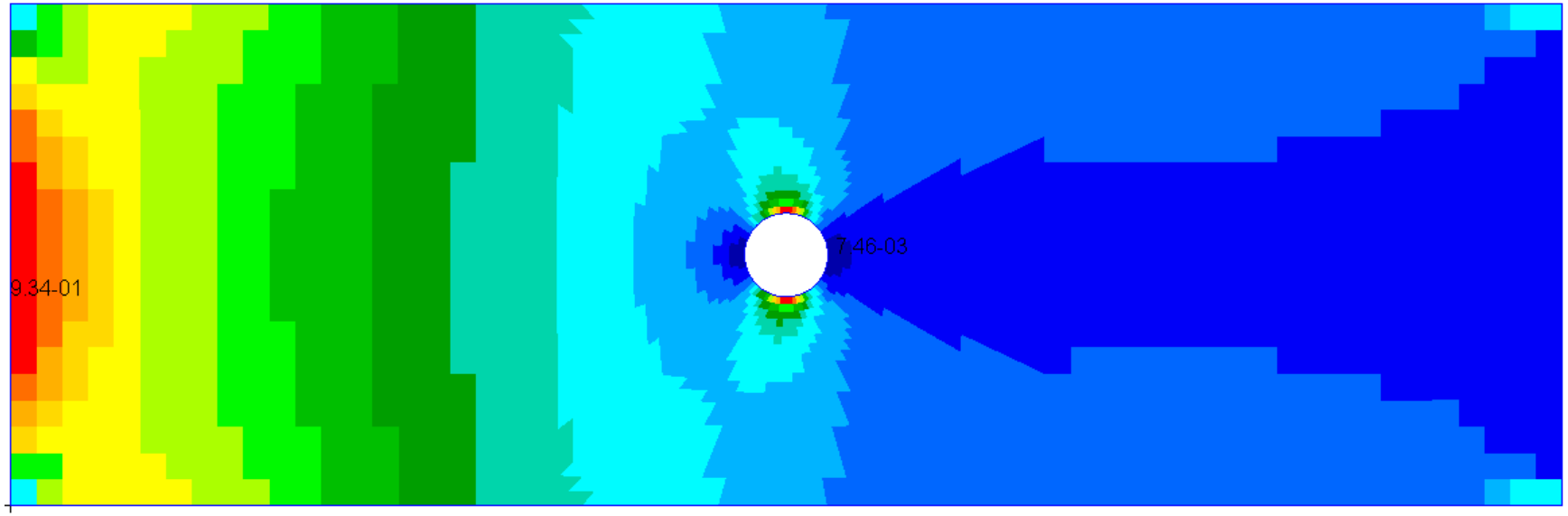
After



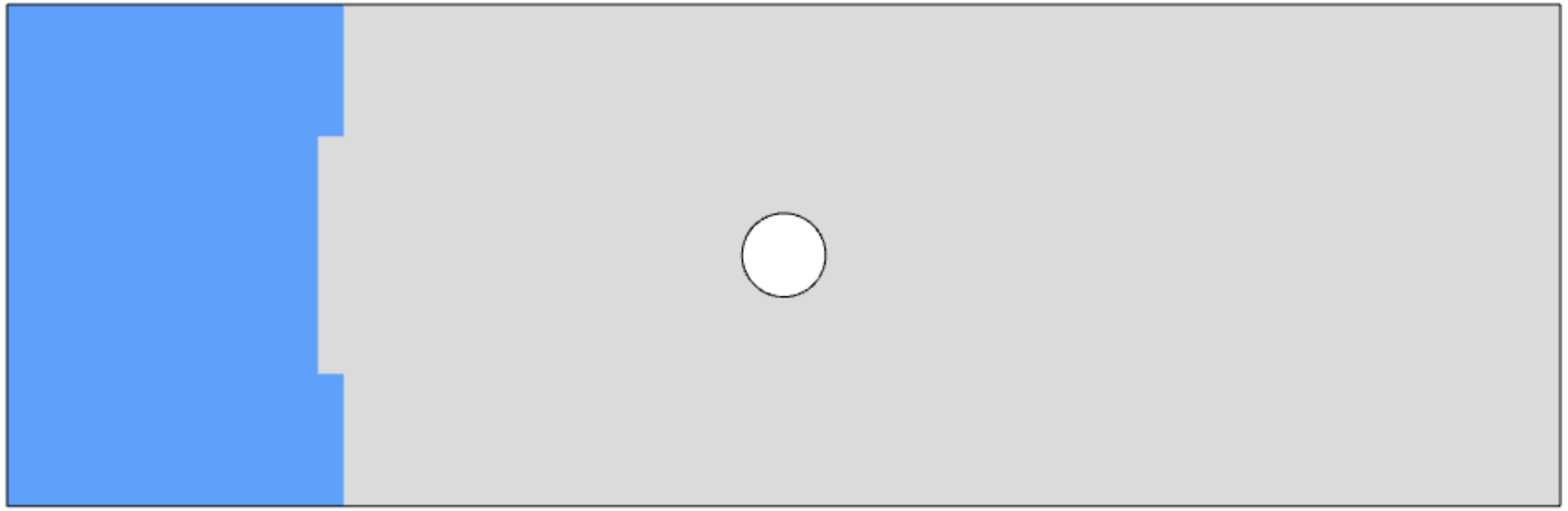
Ply Shape Editing: Candidate 2 for 90°

- The ply shape candidate takes a form that aligns with the contour of the maximum failure index plot

Maximum Failure Index

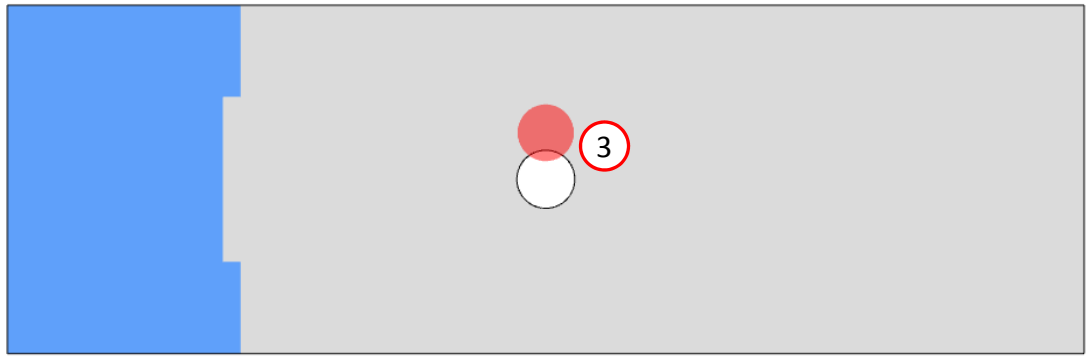


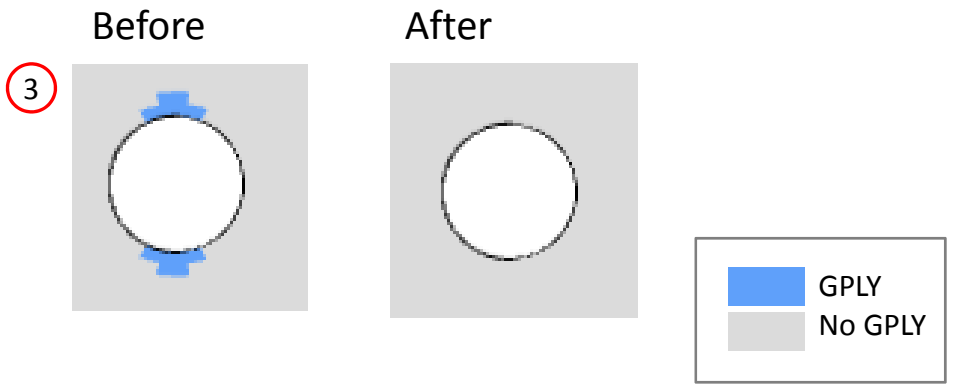
Ply Shape Candidate 2

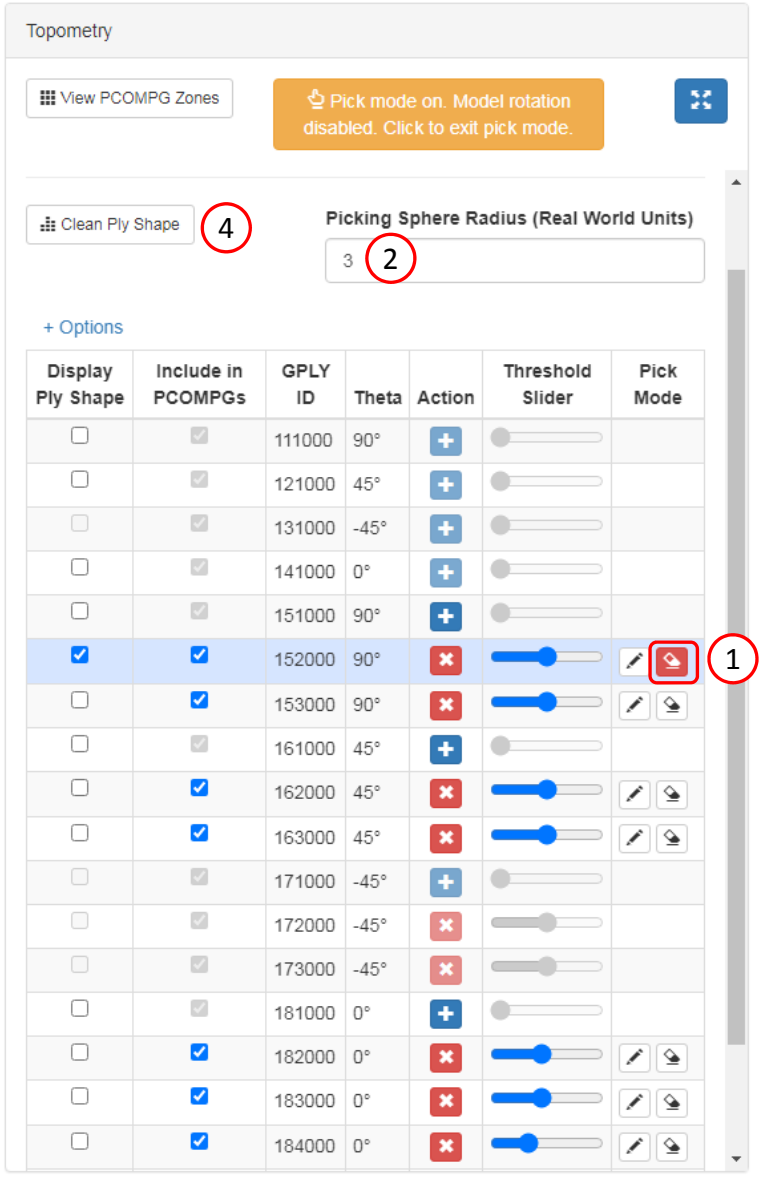


Ply Shape Editing: 90°, Candidate 2

1. Click the indicated icon
2. A red sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to approximately 3 .
3. Press and hold the left mouse button, and drag the sphere to remove the ply from the indicated region.
4. Click Clean Ply Shape

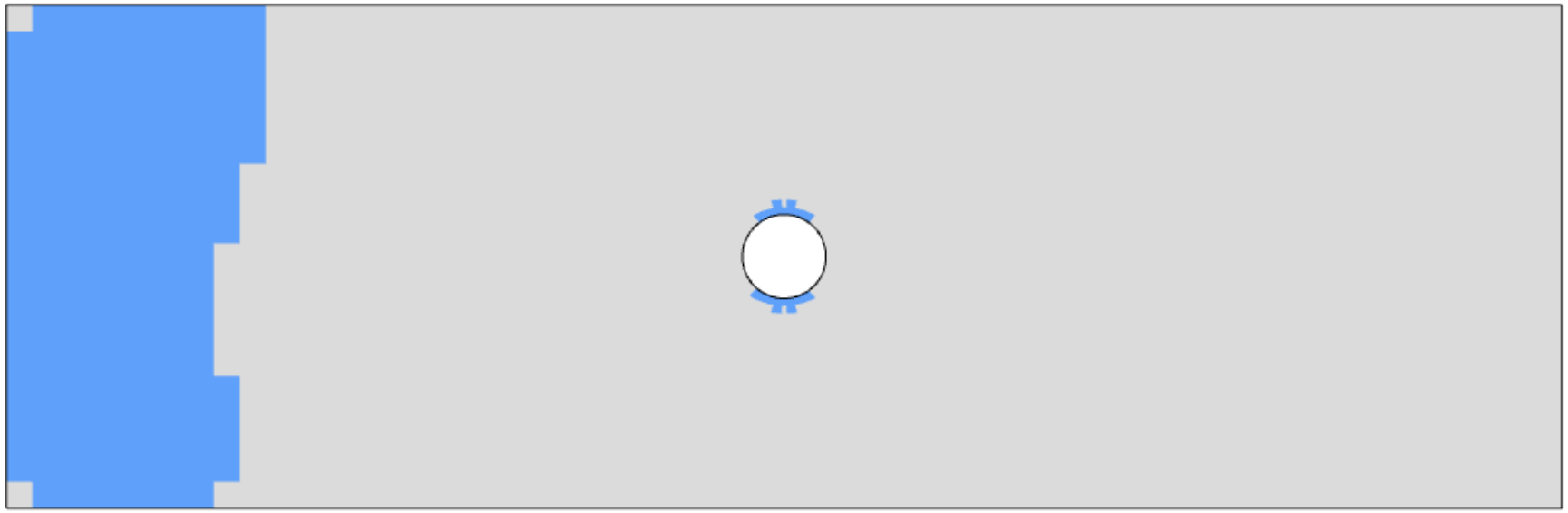




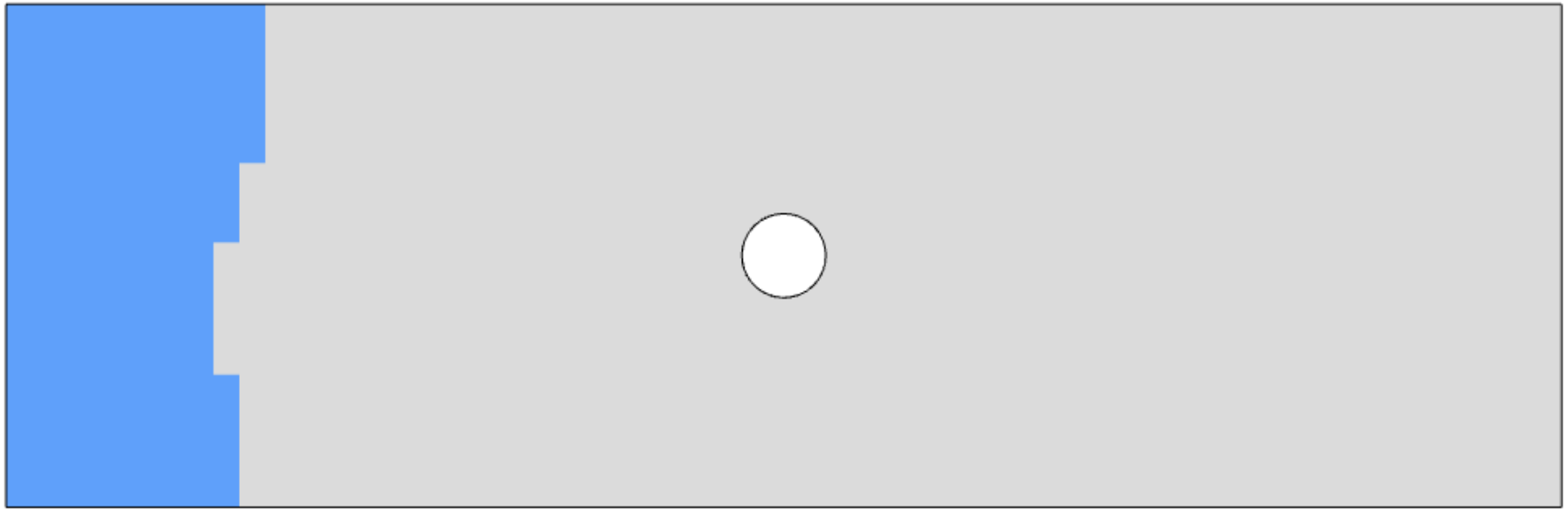


Ply Shape Editing: Candidate 2 for 45°

Before



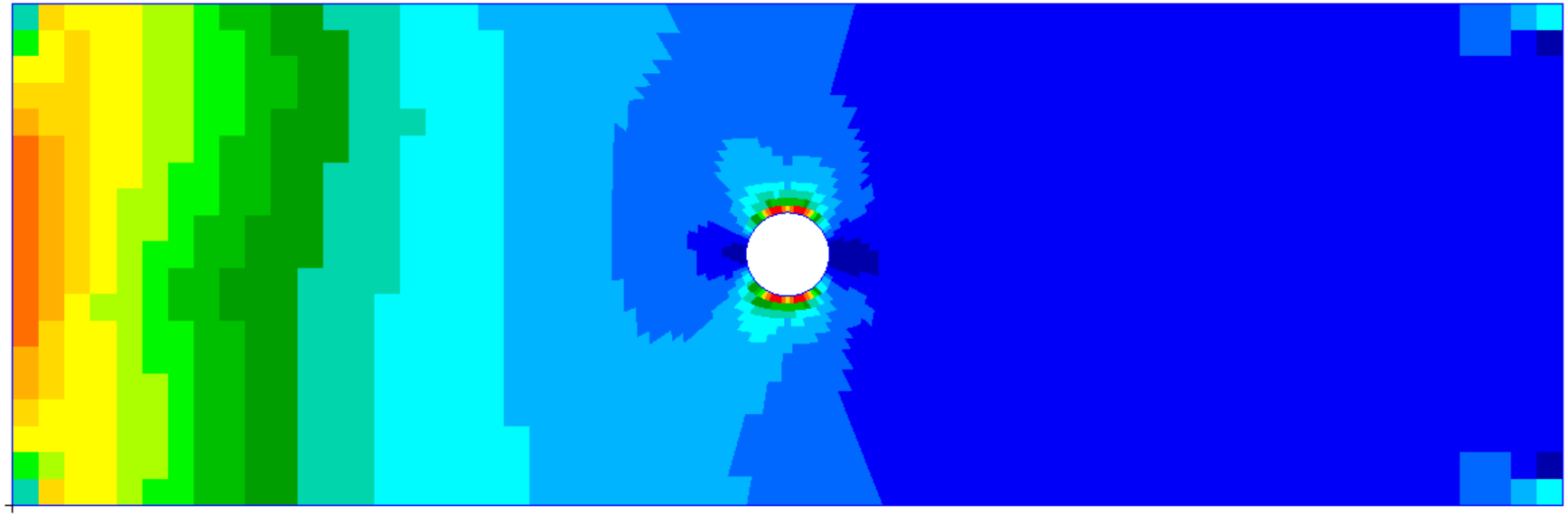
After



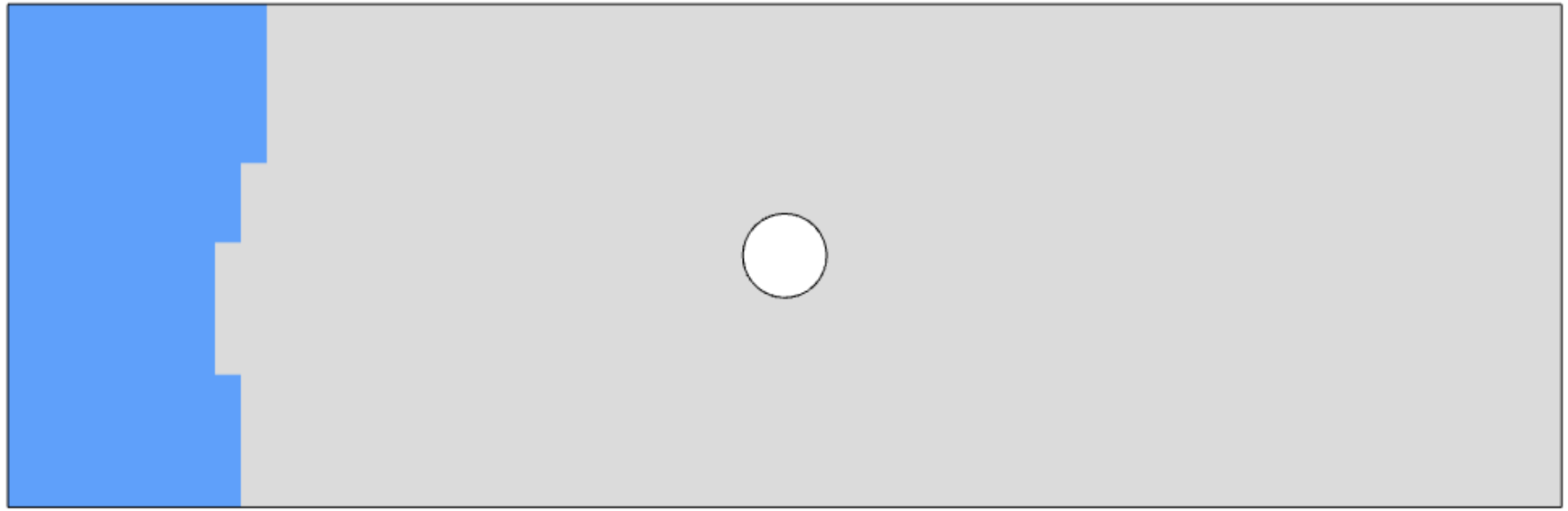
Ply Shape Editing: Candidate 2 for 45°

- The ply shape candidate takes a form that aligns with the contour of the maximum failure index plot
- The values used are the maximum failure indices of +45° and -45° plies

Maximum Failure Index

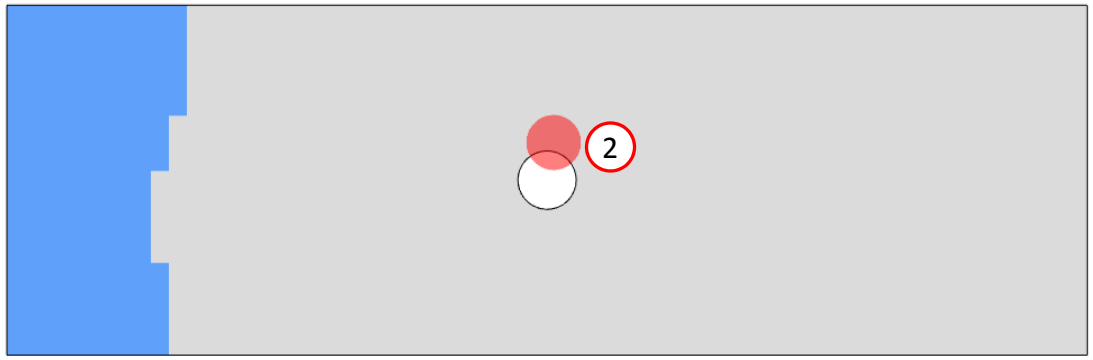


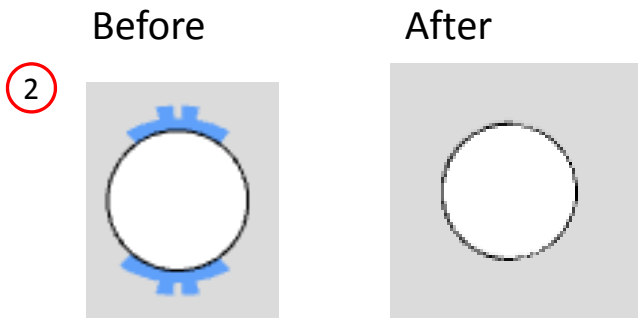
Ply Shape Candidate 2

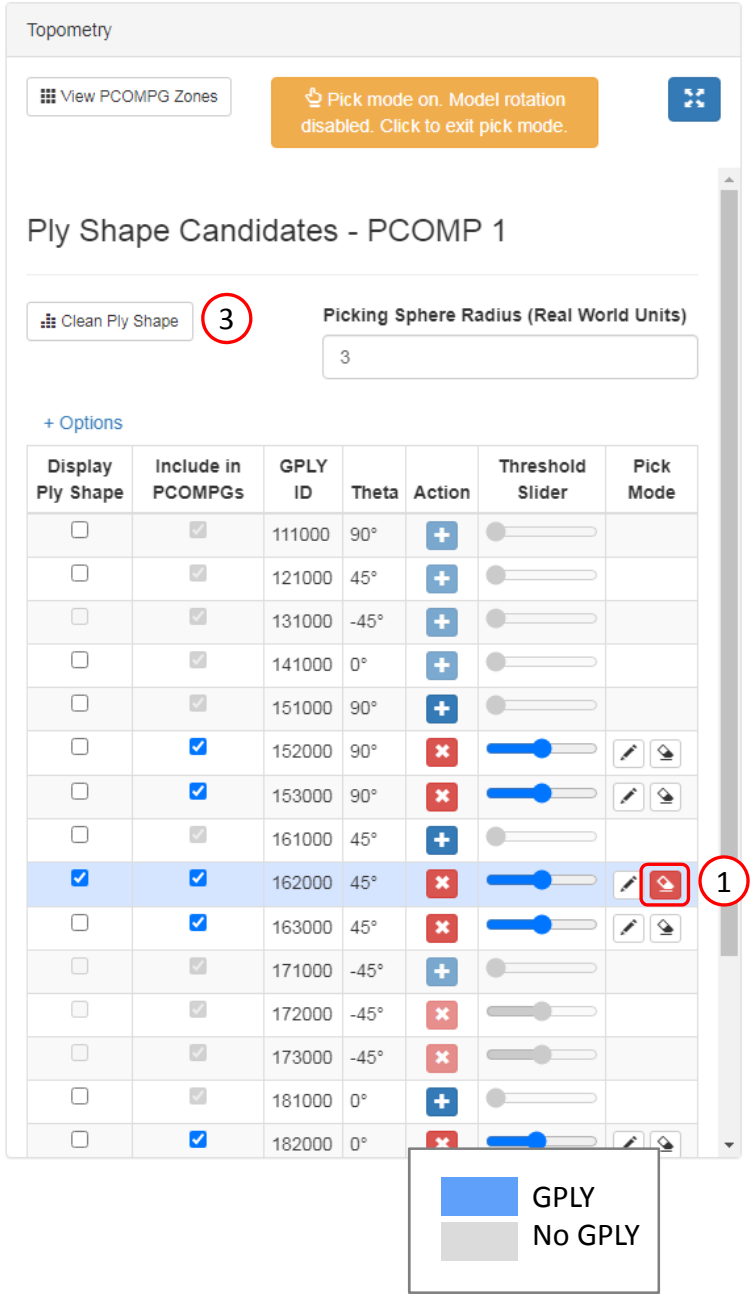


Ply Shape Editing: Candidate 2 for 45°

1. Click the indicated icon
2. A red sphere appears and moves with mouse cursor. Press and hold the left mouse button, and drag the sphere to remove the ply from the indicated region.
3. Click Clean Ply Shape

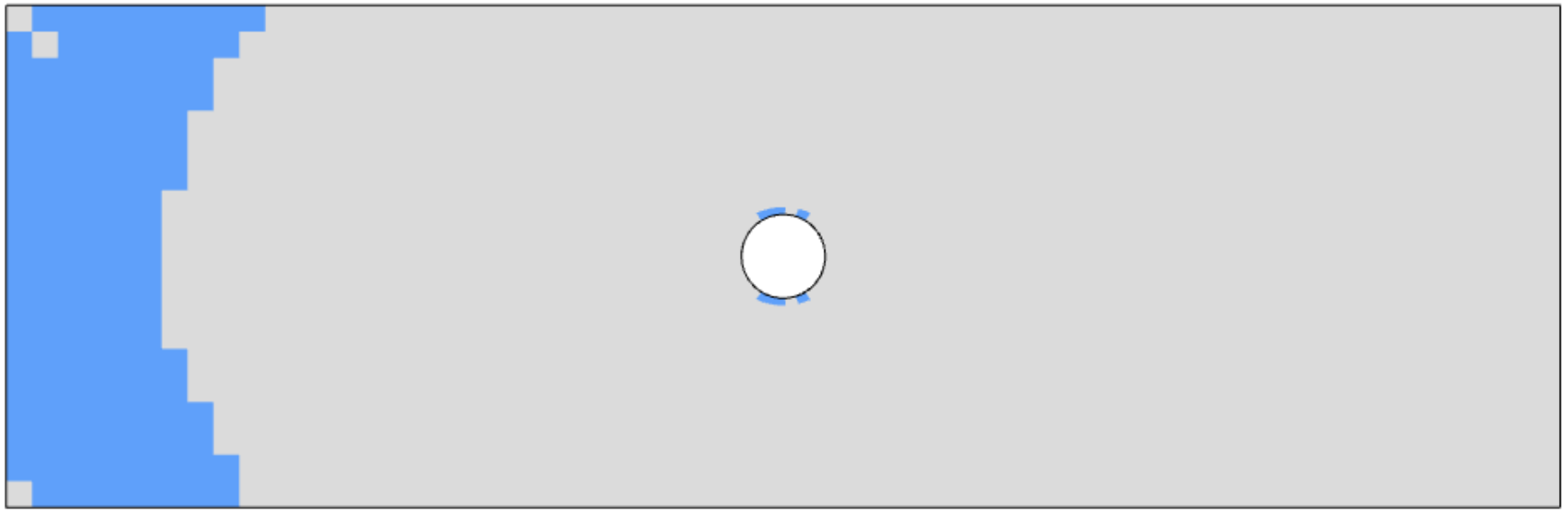




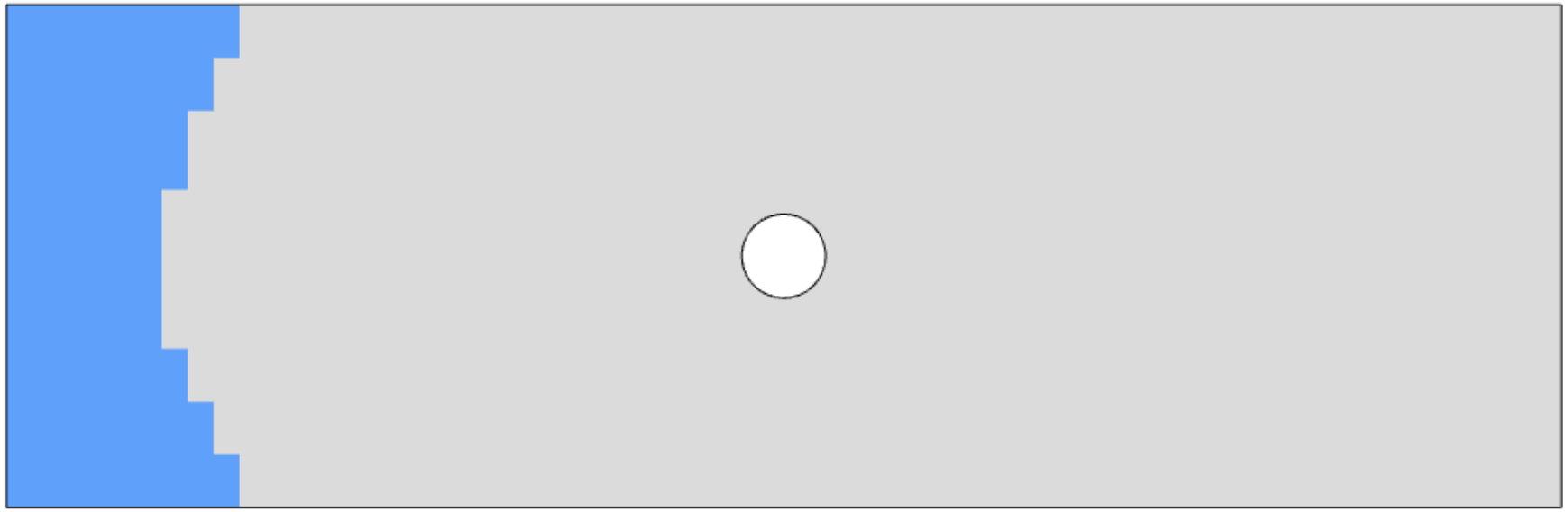


Ply Shape Editing: Candidate 2 for 0°

Before



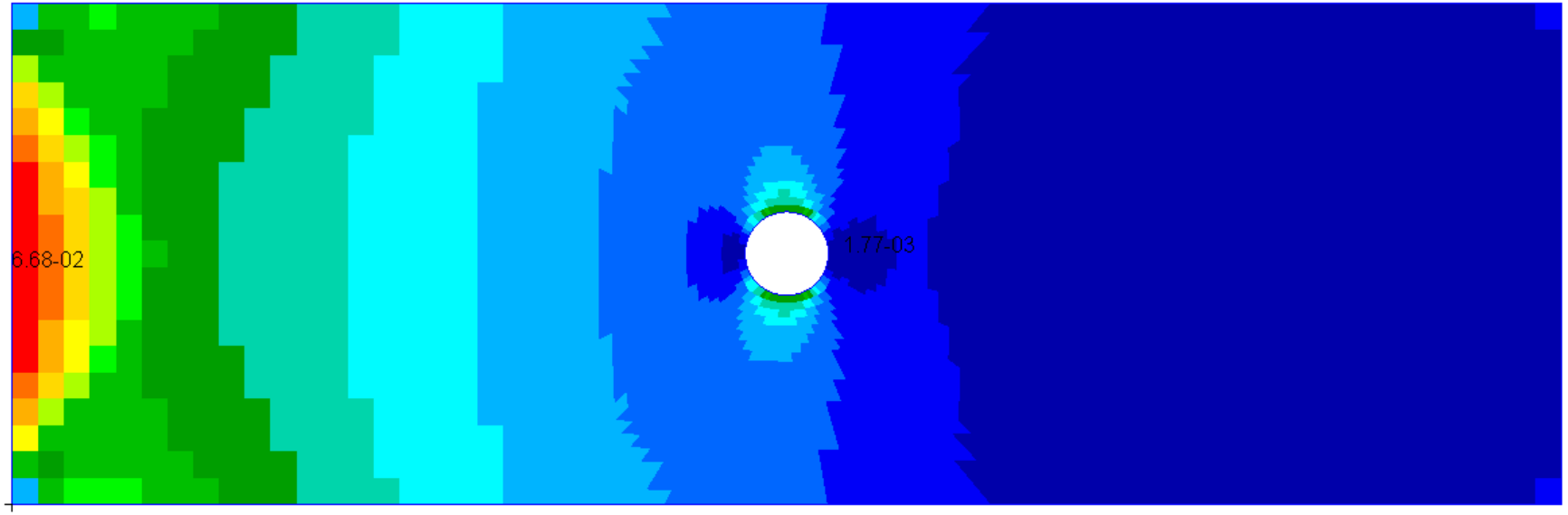
After



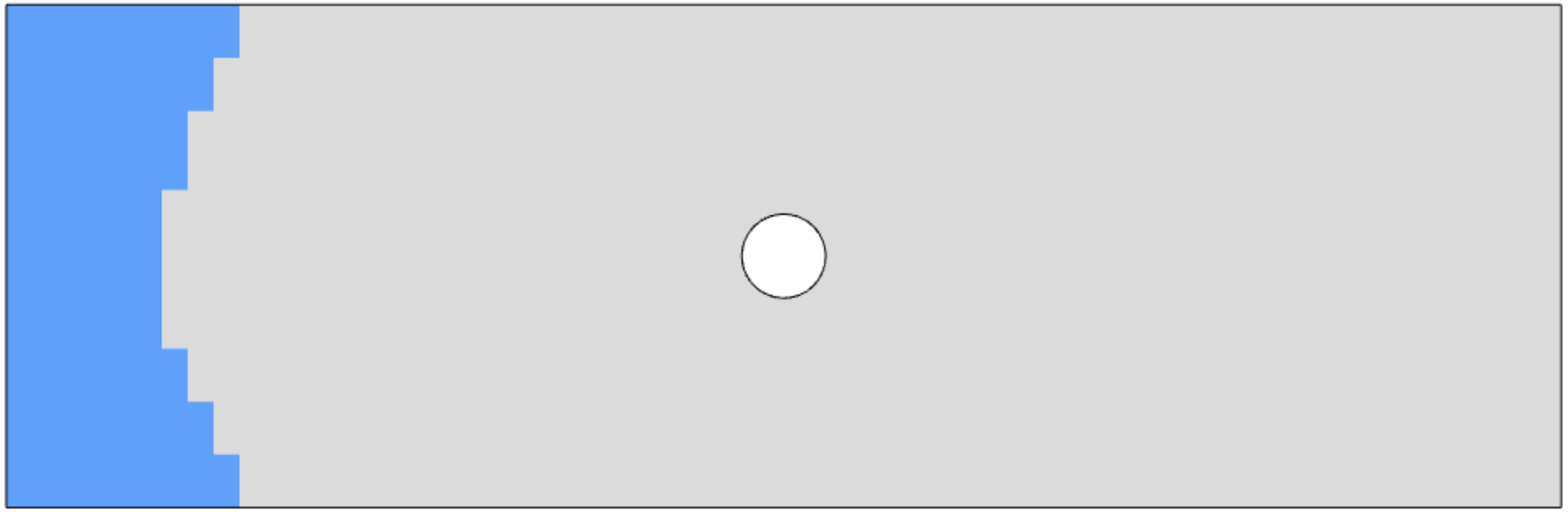
Ply Shape Editing: Candidate 2 for 0°

- The ply shape candidate takes a form that aligns with the contour of the maximum failure index plot
- The values used are the maximum failure indices of the 0° ply

Maximum Failure Index

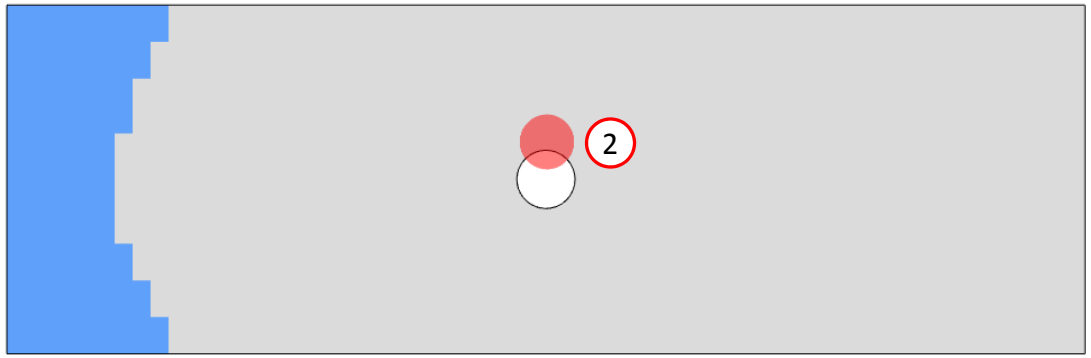


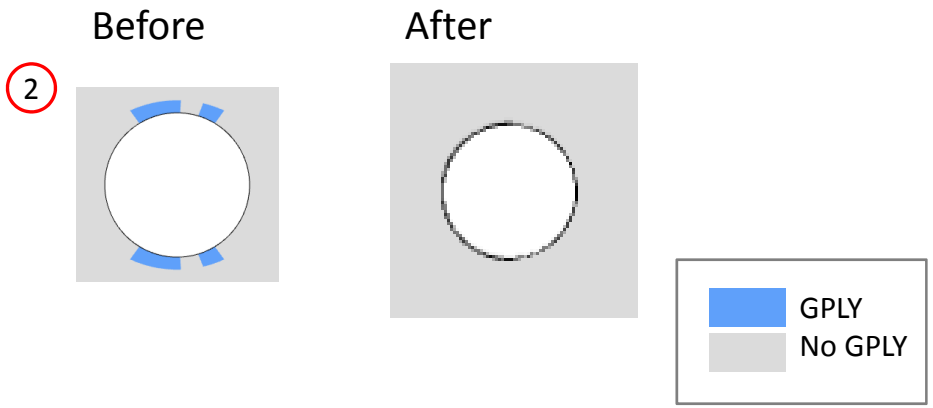
Ply Shape Candidate 2

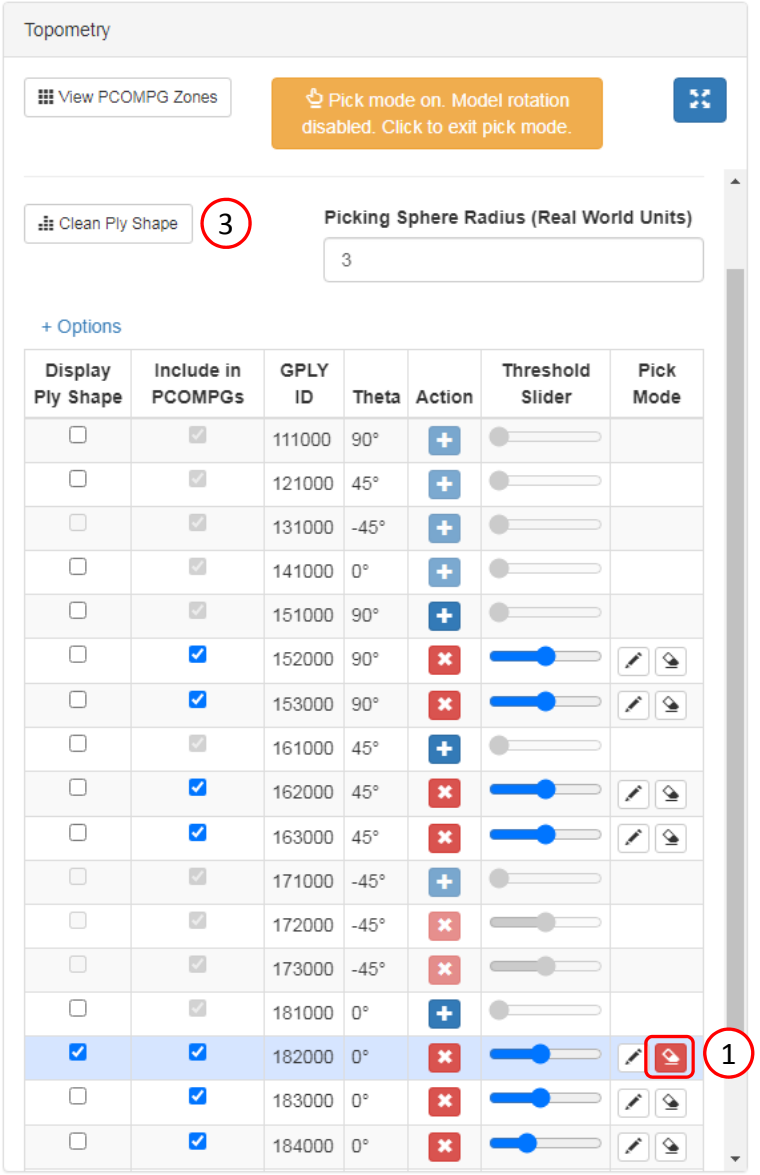


Ply Shape Editing: Candidate 2 for 0°

1. Click the indicated icon
2. A red sphere appears and moves with mouse cursor. Press and hold the left mouse button, and drag the sphere to remove the ply from the indicated region.
3. Click Clean Ply Shape 3 times





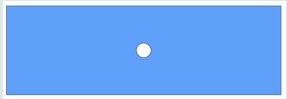
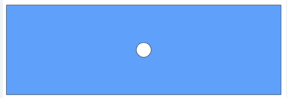
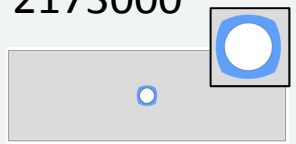
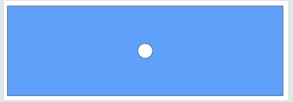
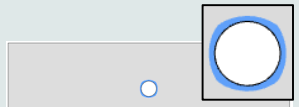


Ply Shape Candidates Creation

1. The indicated ply shape candidates will be created

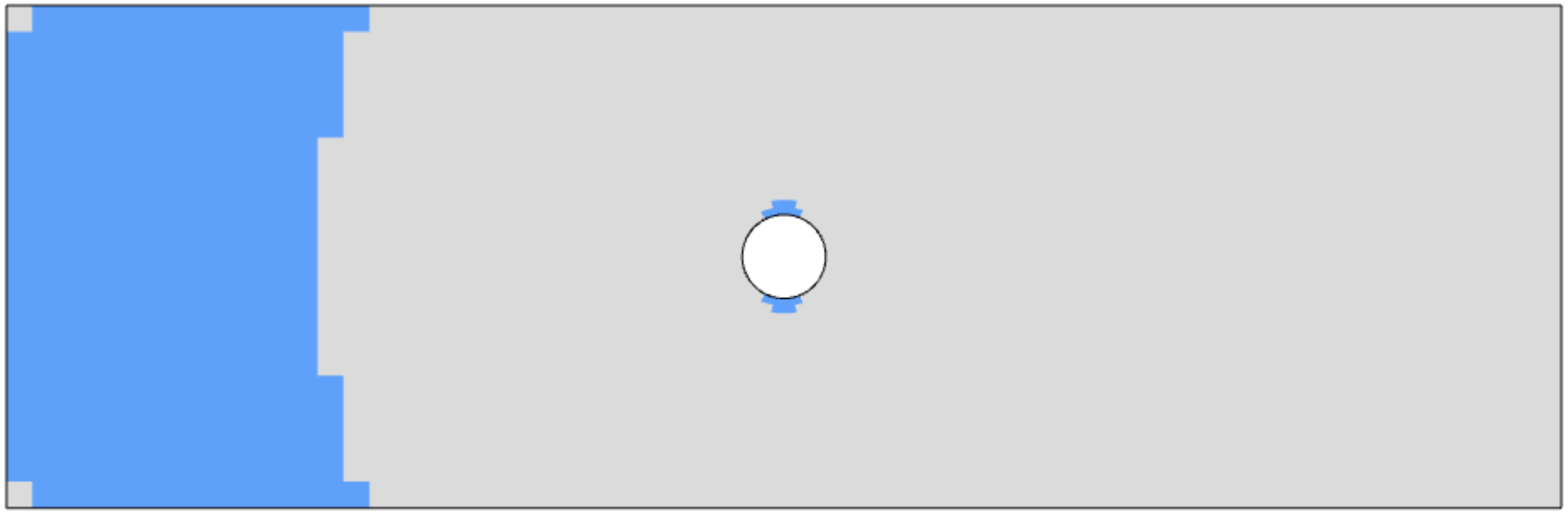
1

Ply Shape

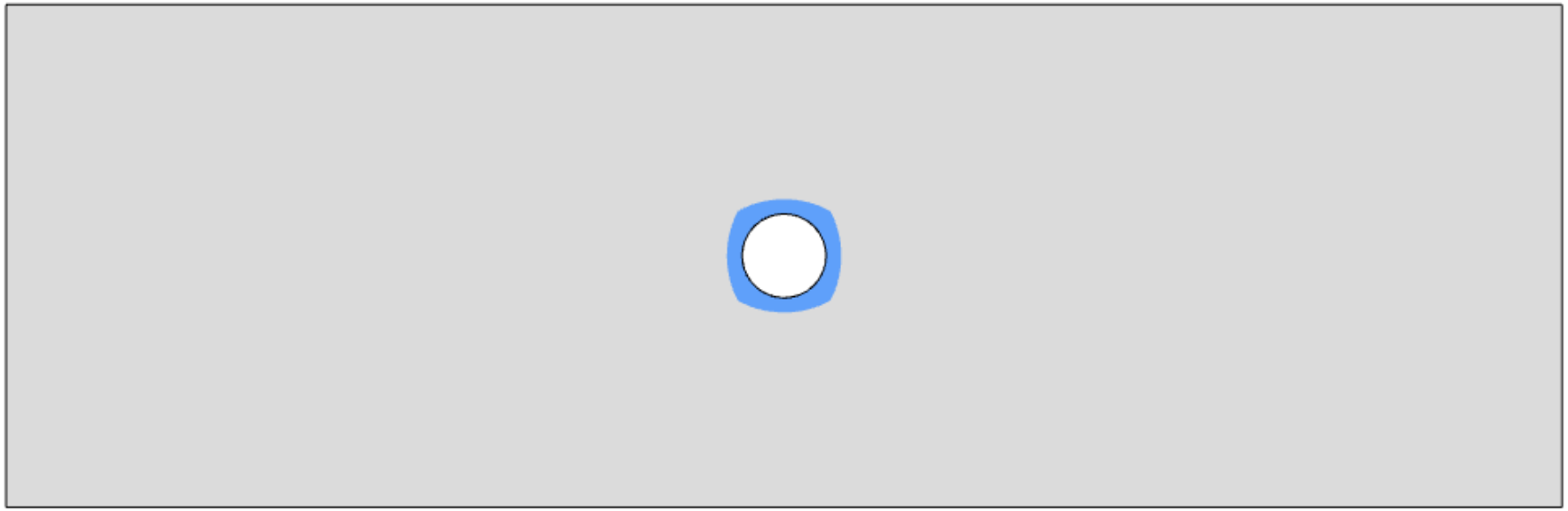
Layer, Theta	Ply Shape Candidate 1	Ply Shape Candidate 2	Ply Shape Candidate 3	Ply Shape Candidate 4	Ply Shape Candidate 5
5 90°	151000, 2151000 	152000, 2152000 	153000, 2153000 		
6, 7 ±45°	161000, 2161000 171000, 2171000 	162000, 2162000 172000, 2172000 	163000, 2163000 173000, 2173000 		
8 0°	181000, 2181000 	182000, 2182000 	183000, 2183000 	184000, 2184000 	185000, 2185000 

Ply Shape Editing: Candidate 3 for 90°

Before



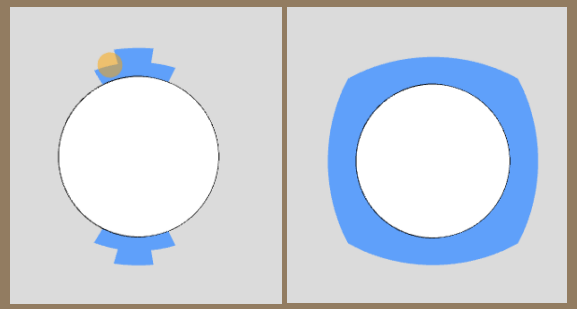
After



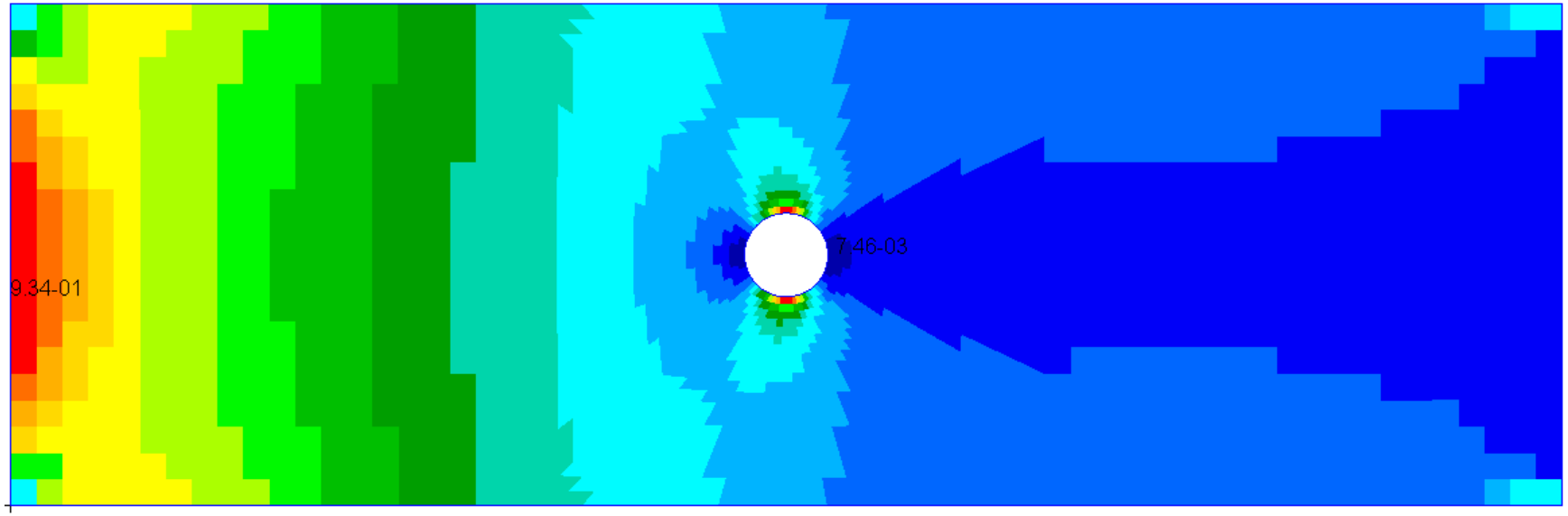
Ply Shape Editing: Candidate 3 for 90°

- The ply shape candidate takes a form that aligns with the contour of the maximum failure index plot

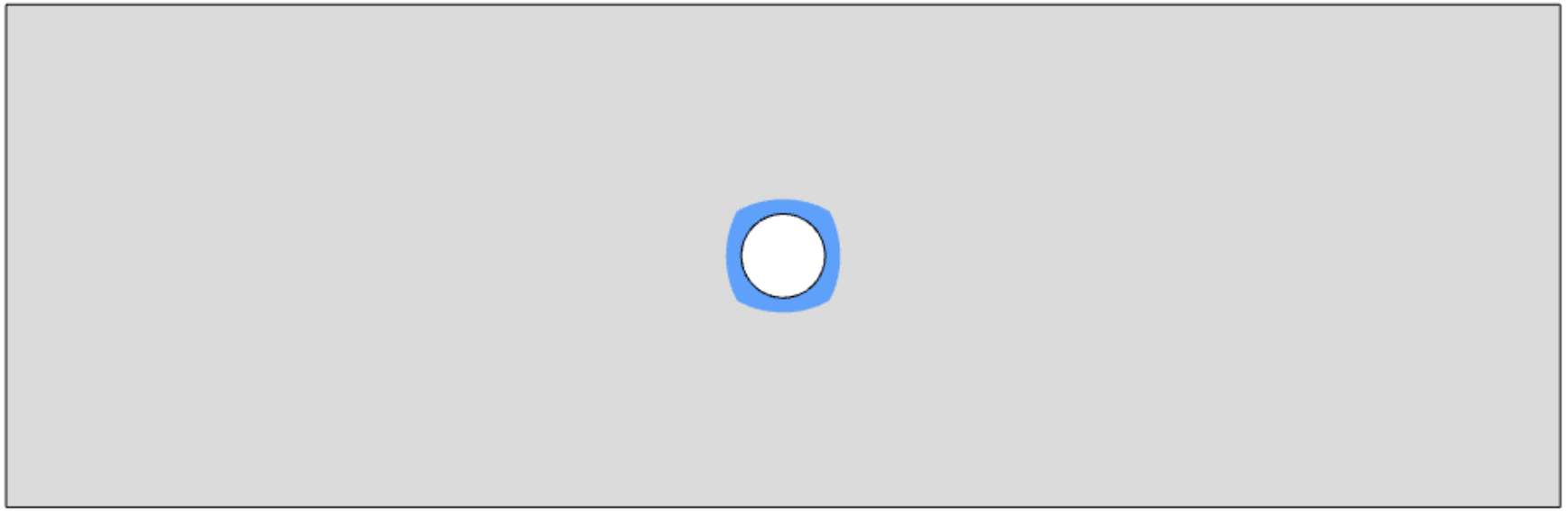
- Below are possible candidate shapes. The shape in the bottom left follows the contours of the failure index but is difficult to manufacture. The shape in the bottom right is more manufacturable and overlaps the same region region.



Maximum Failure Index

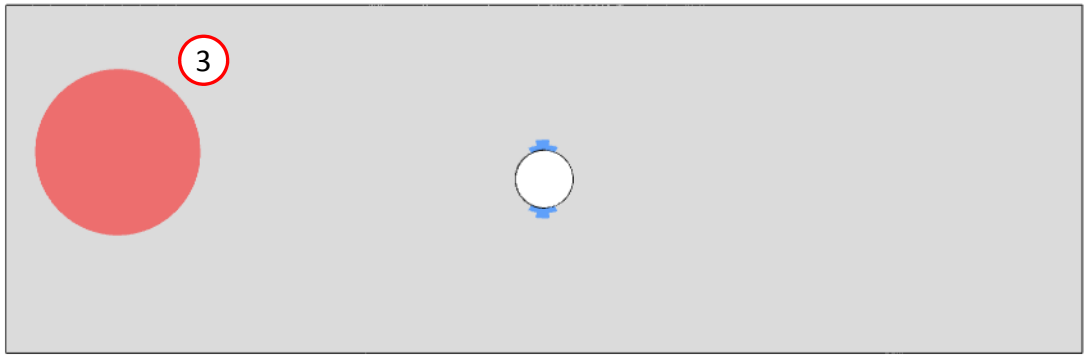


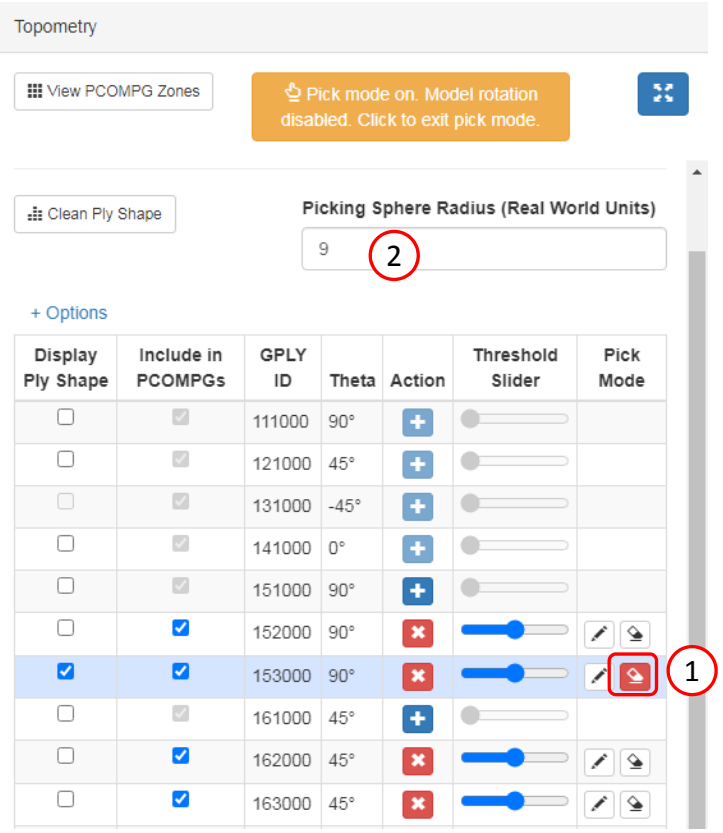
Ply Shape Candidate 2



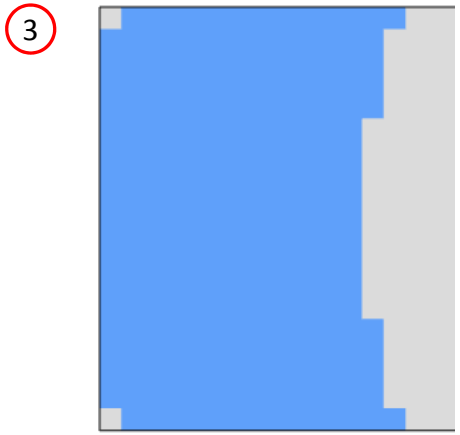
Ply Shape Editing: 90°, Candidate 3

1. Click the indicated icon
2. A red sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to approximately 9 .
3. Press and hold the left mouse button, and drag the sphere to remove the ply from the left side.

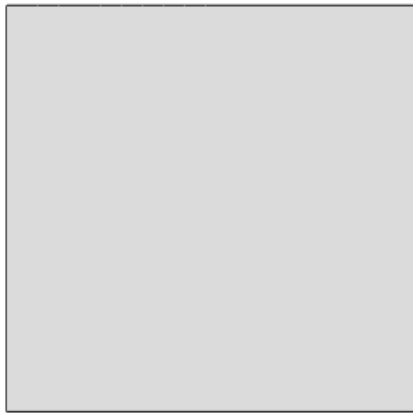


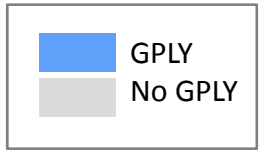


Before



After



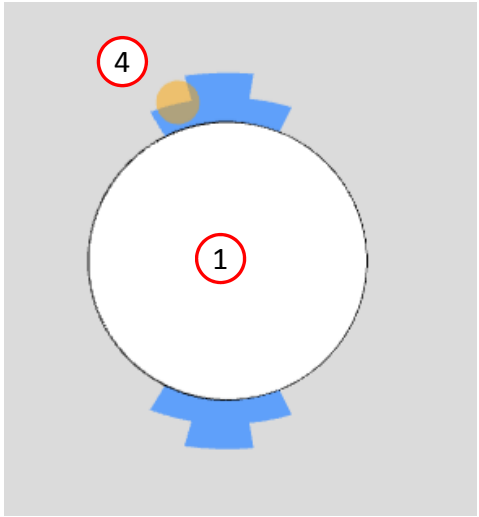


Ply Shape Editing: 90°, Candidate 3

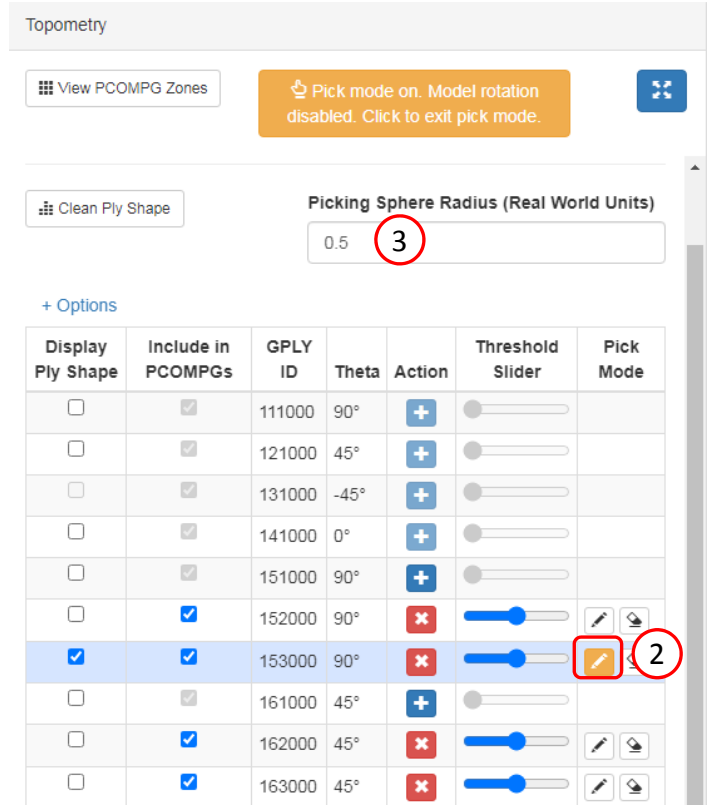
1. Use the scroll wheel on the mouse to zoom in to the hole
2. Click the indicated icon
3. A yellow sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to 0.5 .
4. Press and hold the left mouse button, and drag the mouse to move the sphere and add the ply around the hole.

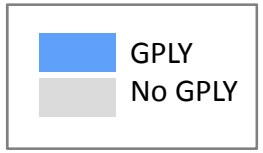
- If a ply shape is spread over the wrong element, use the erase option (red sphere) to remove the ply shape from unwanted regions.

Before



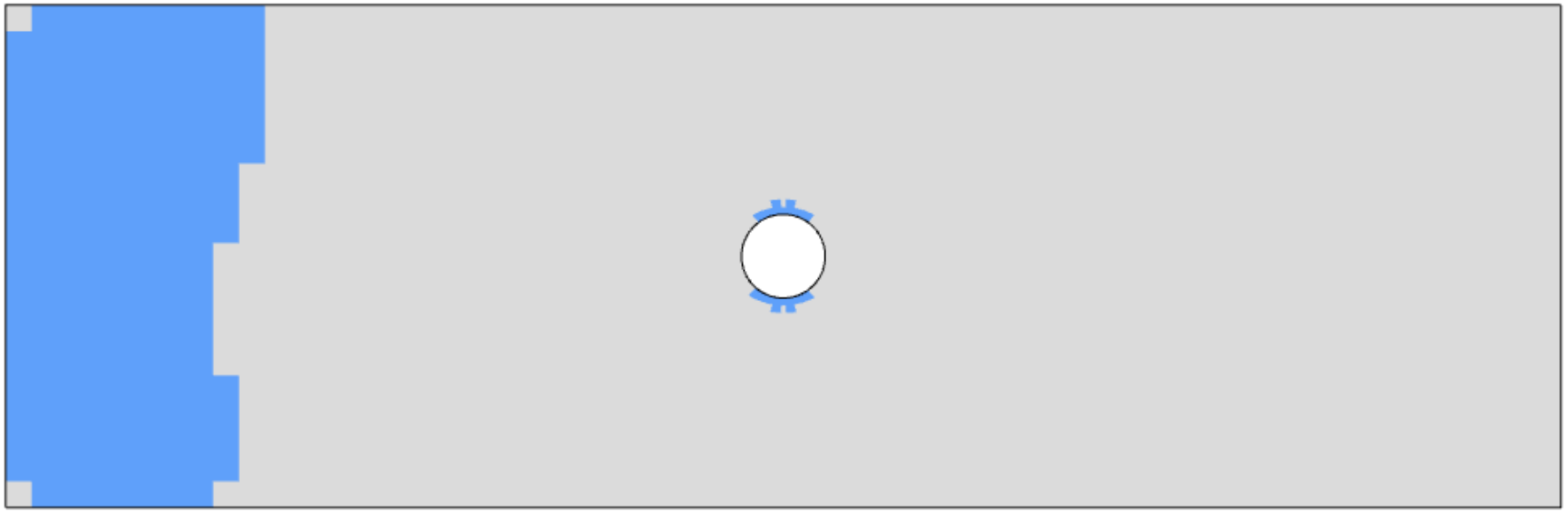
After



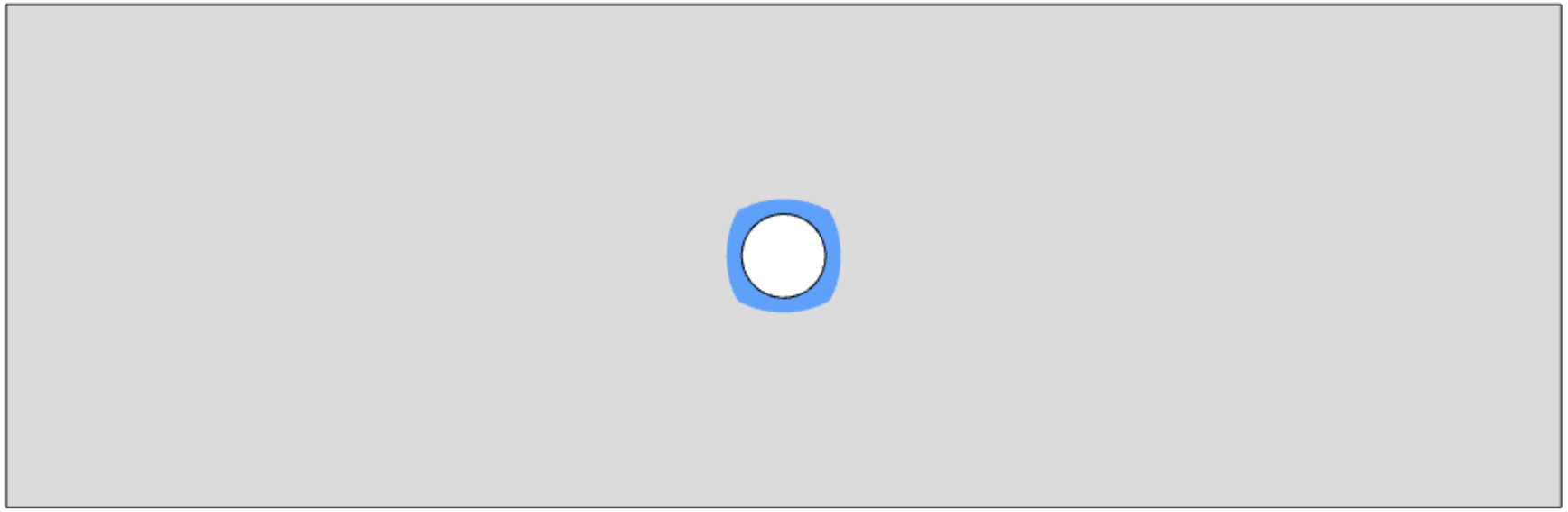


Ply Shape Editing: Candidate 3 for 45°

Before



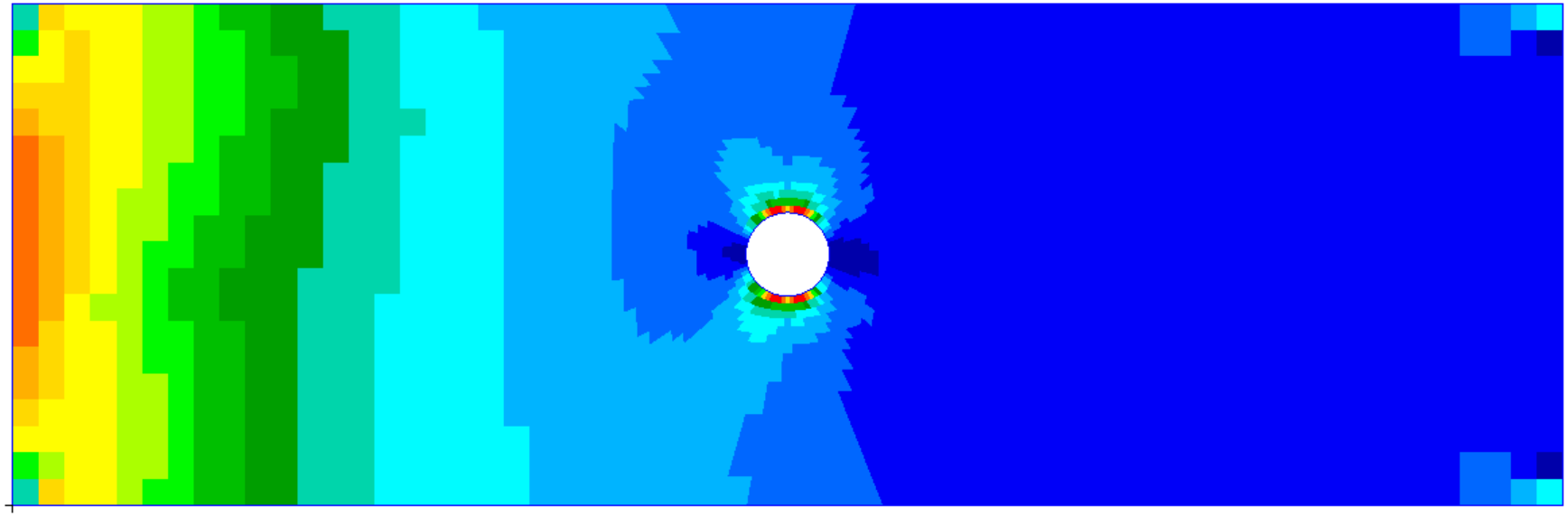
After



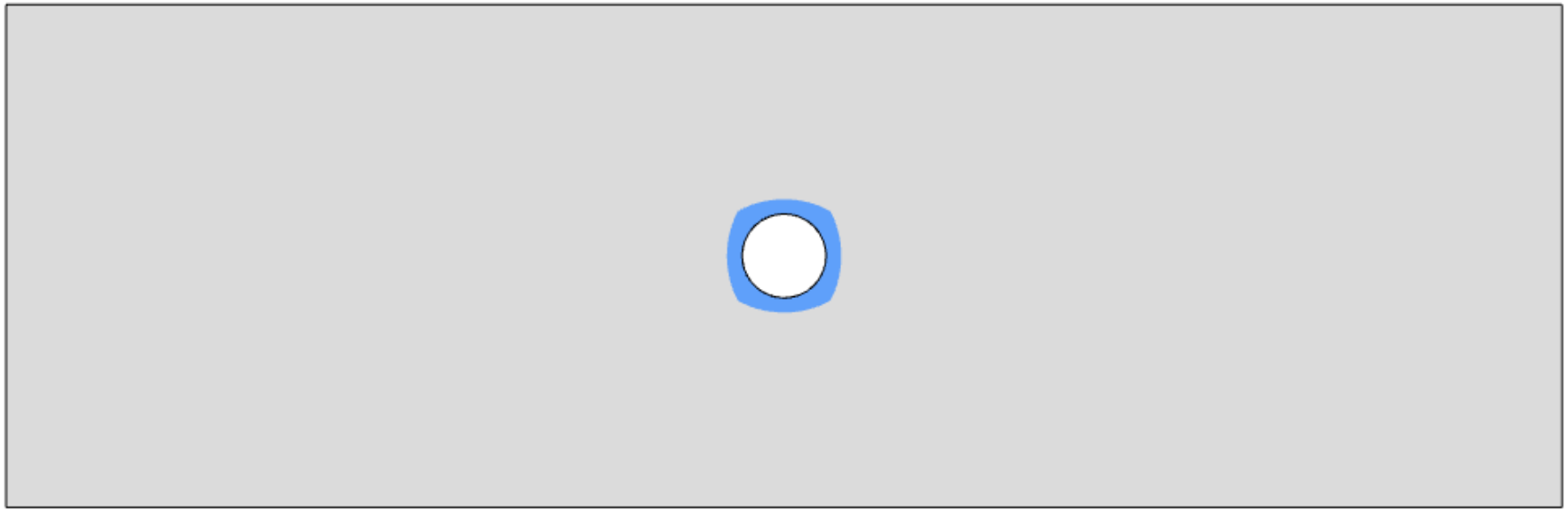
Ply Shape Editing: Candidate 3 for 45°

- The ply shape candidate takes a form that aligns with the contour of the maximum failure index plot
- The values used are the maximum failure indices of +45° and -45°

Maximum Failure Index

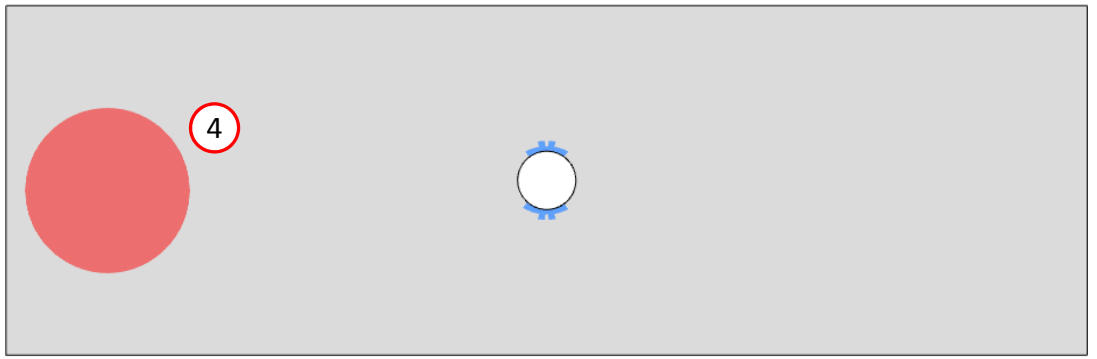


Ply Shape Candidate 2



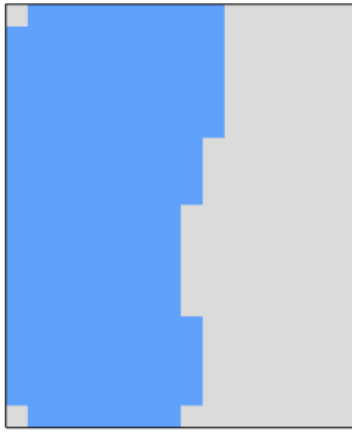
Ply Shape Editing: 45°, Candidate 3

1. Click Fit Model to view the full model (not shown)
2. Click the indicated icon
3. A red sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to approximately 9 .
4. Press and hold the left mouse button, and drag the sphere to remove the ply from the left side.

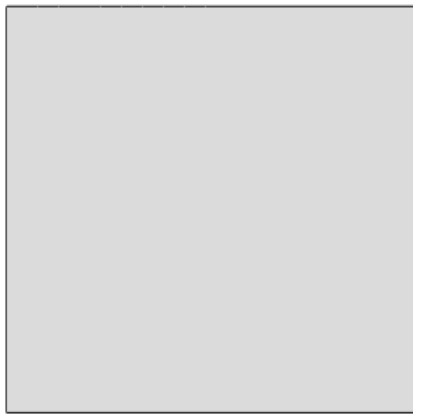


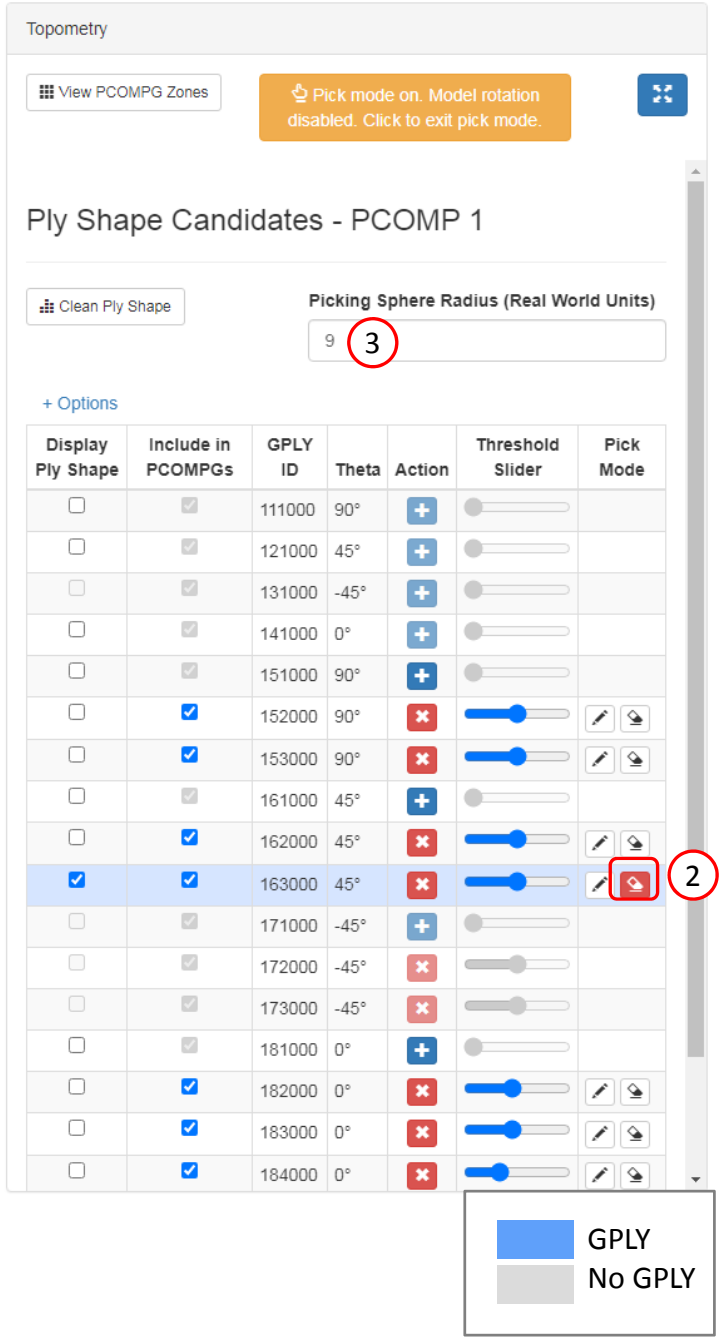
Before

4



After



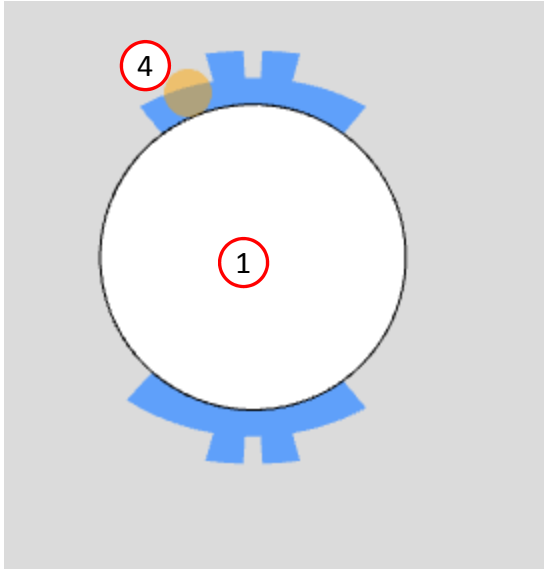


Ply Shape Editing: 45°, Candidate 3

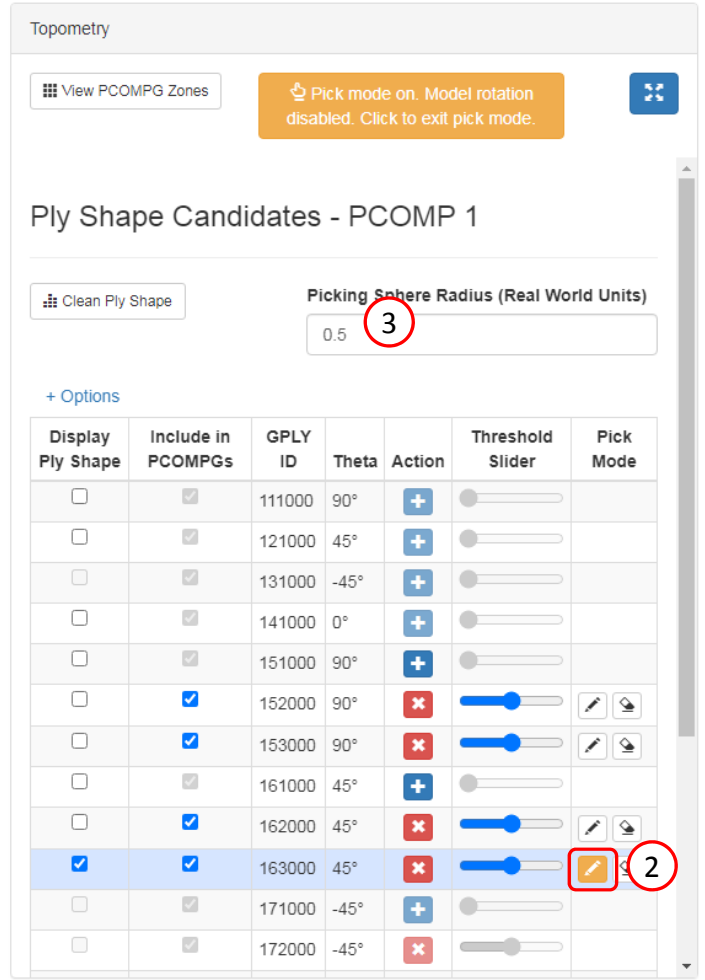
1. Use the scroll wheel on the mouse to zoom in to the hole
2. Click the indicated icon
3. A yellow sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to 0.5 .
4. Press and hold the left mouse button, and drag the mouse to move the sphere and add the ply around the hole.

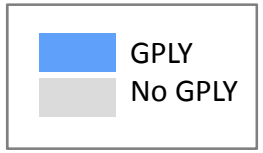
- If a ply shape is spread over the wrong element, use the erase option (red sphere) to remove the ply shape from unwanted regions.

Before



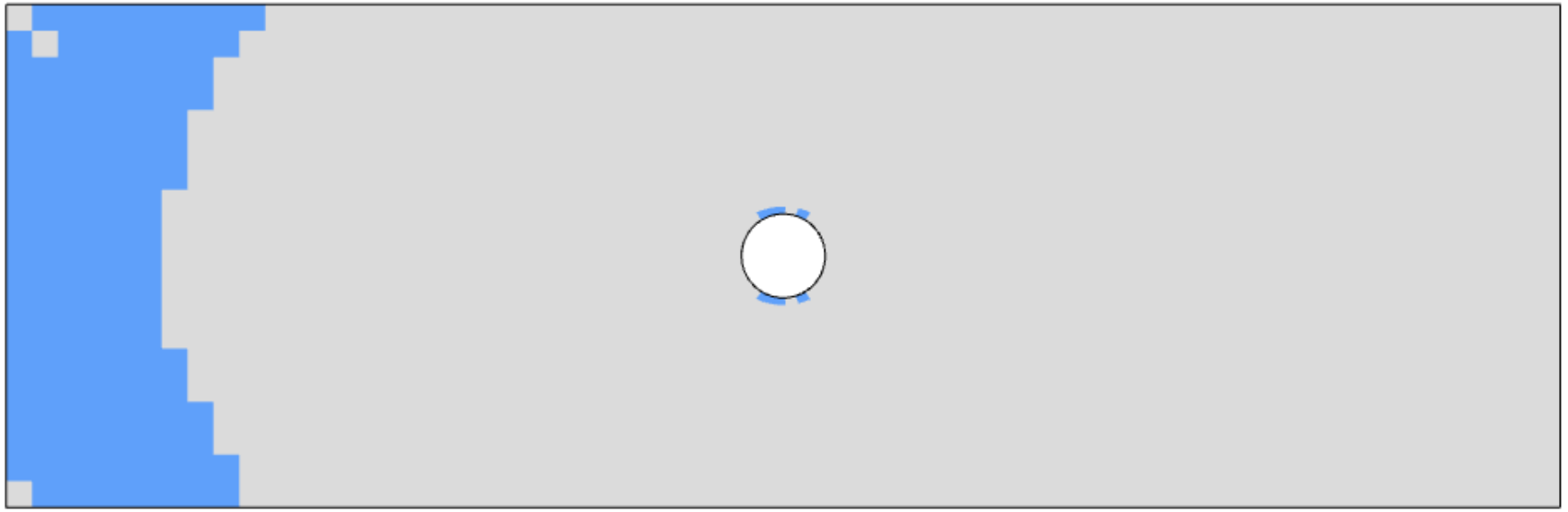
After



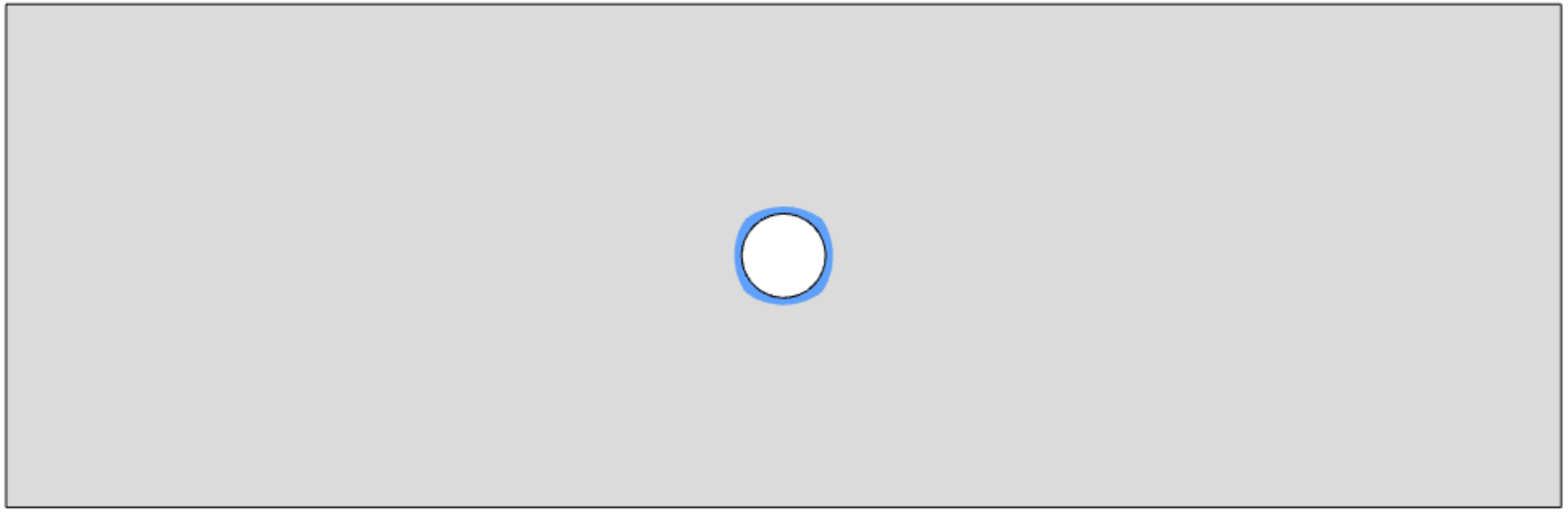


Ply Shape Editing: Candidate 3 for 0°

Before



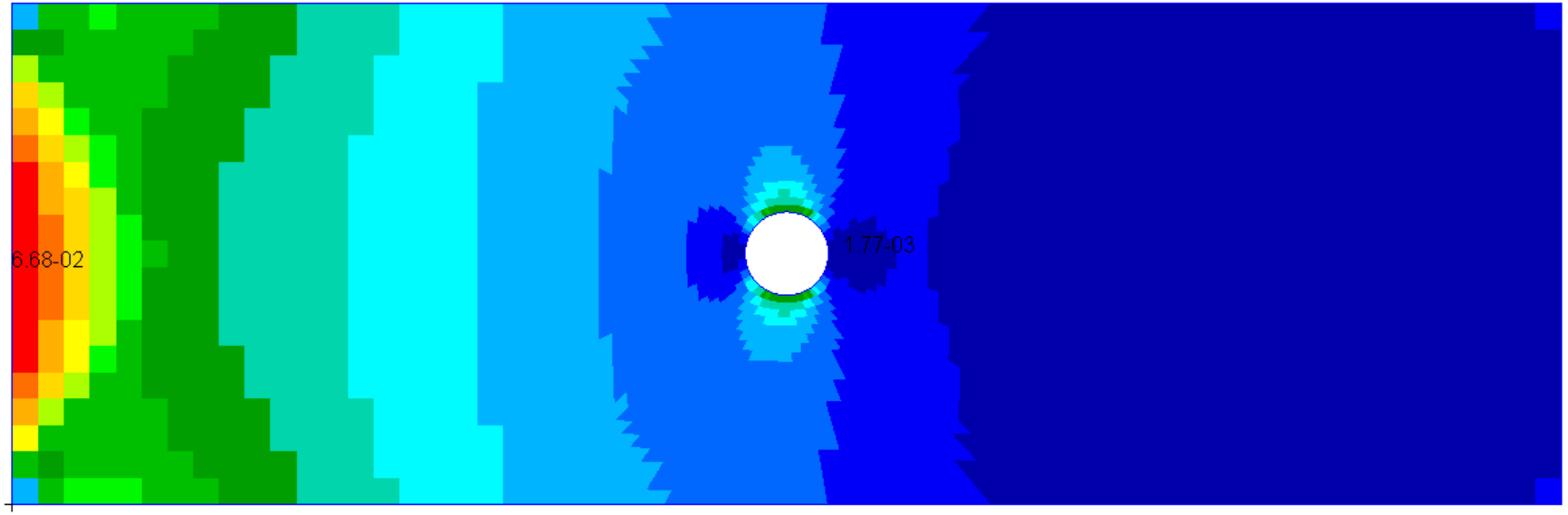
After



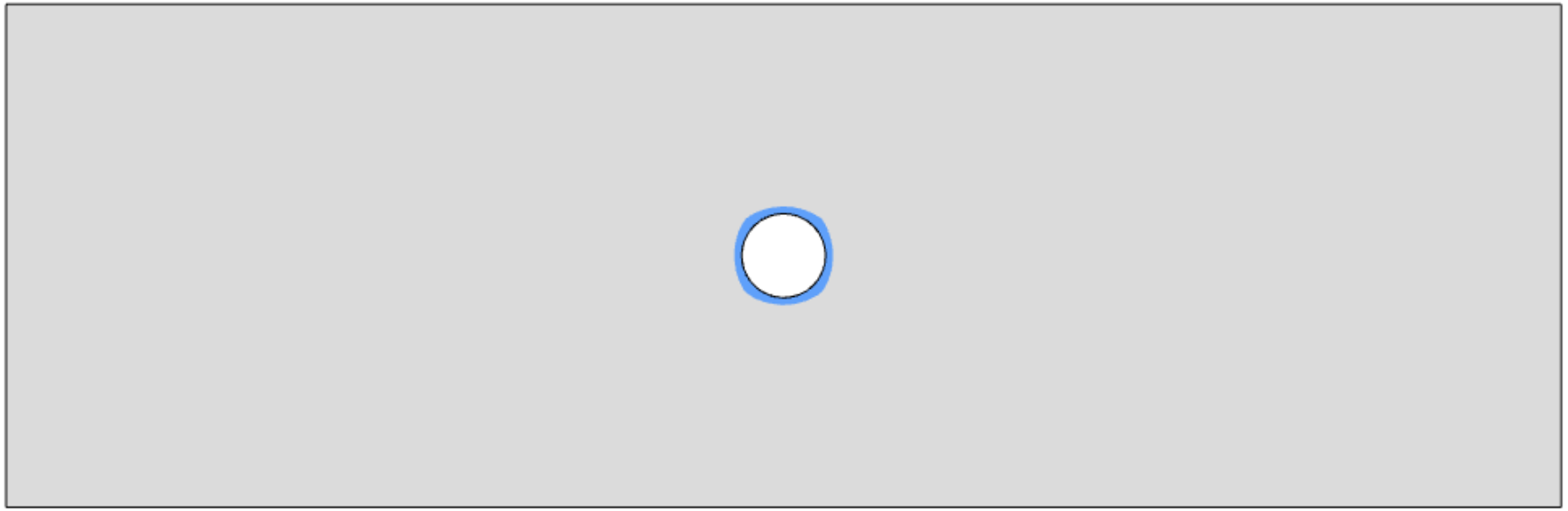
Ply Shape Editing: Candidate 3 for 0°

- The ply shape candidate takes a form that aligns with the contour of the maximum failure index plot
- The values used are the maximum failure indices of the 0° ply

Maximum Failure Index

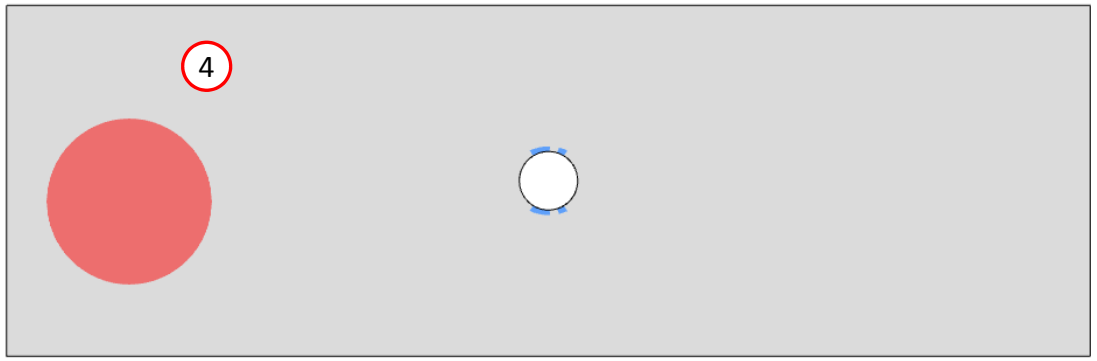


Ply Shape Candidate 2



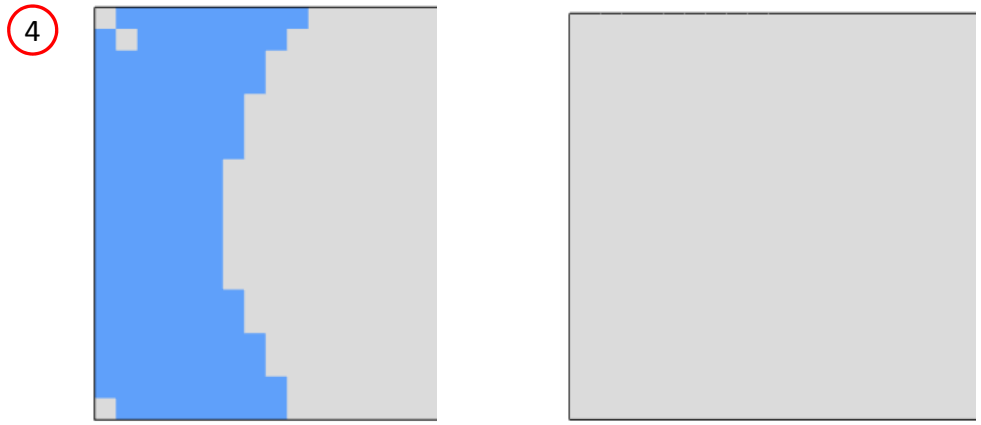
Ply Shape Editing: 0°, Candidate 3

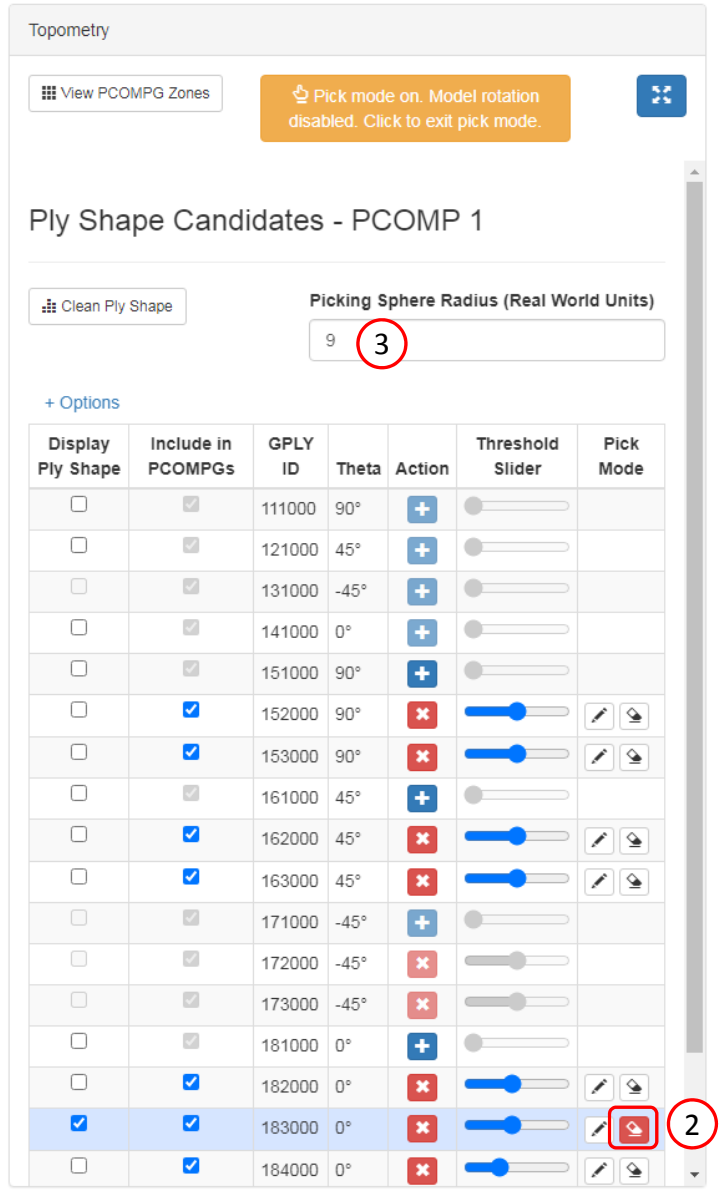
1. Click Fit Model to view the full model (not shown)
2. Click the indicated icon
3. A red sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to approximately 9 .
4. Press and hold the left mouse button, and drag the sphere to remove the ply from the left side.



Before

After





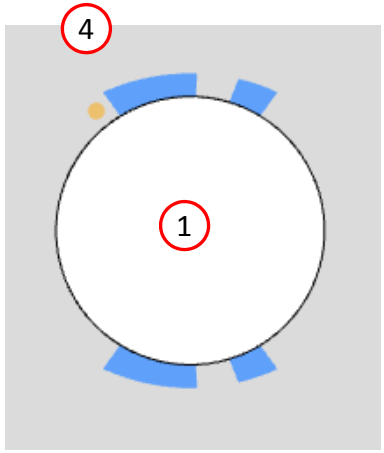
GPLY
No GPLY

Ply Shape Editing: 0°, Candidate 3

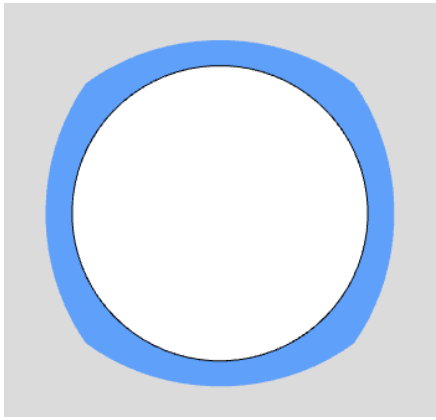
1. Use the scroll wheel on the mouse to zoom in to the hole
2. Click the indicated icon
3. A yellow sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to 0.2 .
4. Press and hold the left mouse button, and drag the mouse to move the sphere and add the ply around the hole.

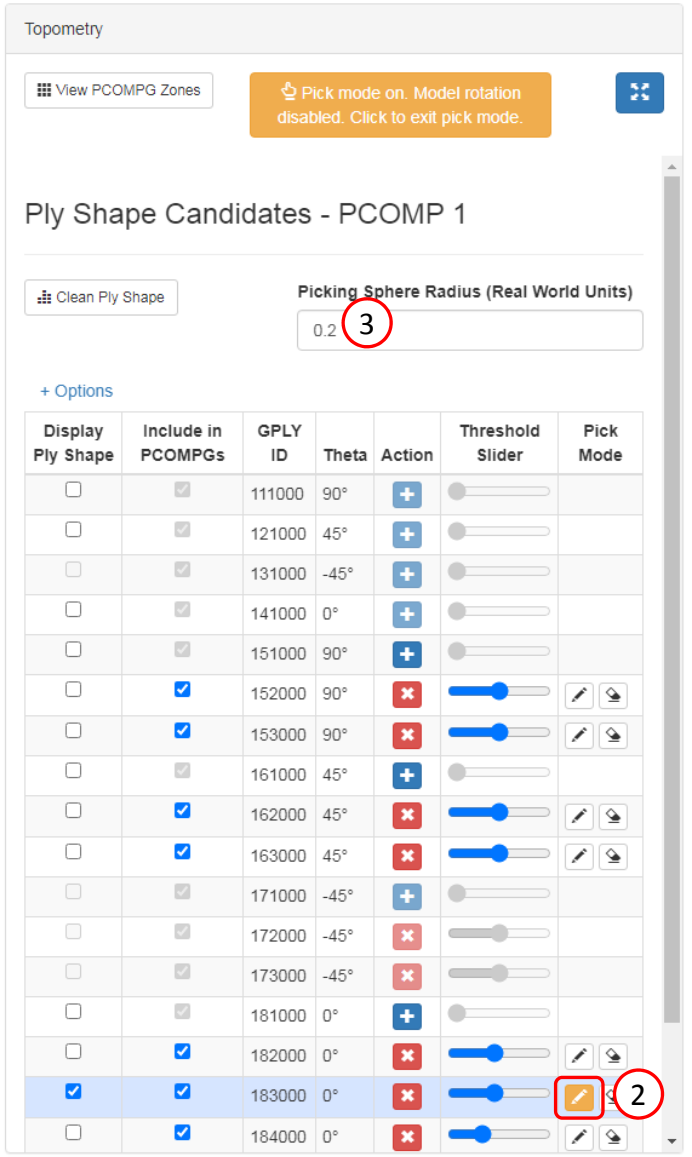
- If a ply shape is spread over the wrong element, use the erase option (red sphere) to remove the ply shape from unwanted regions.

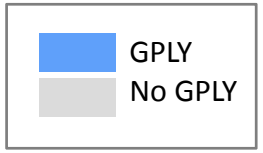
Before



After







Ply Shape Candidates Creation

1. The indicated ply shape candidates will be created

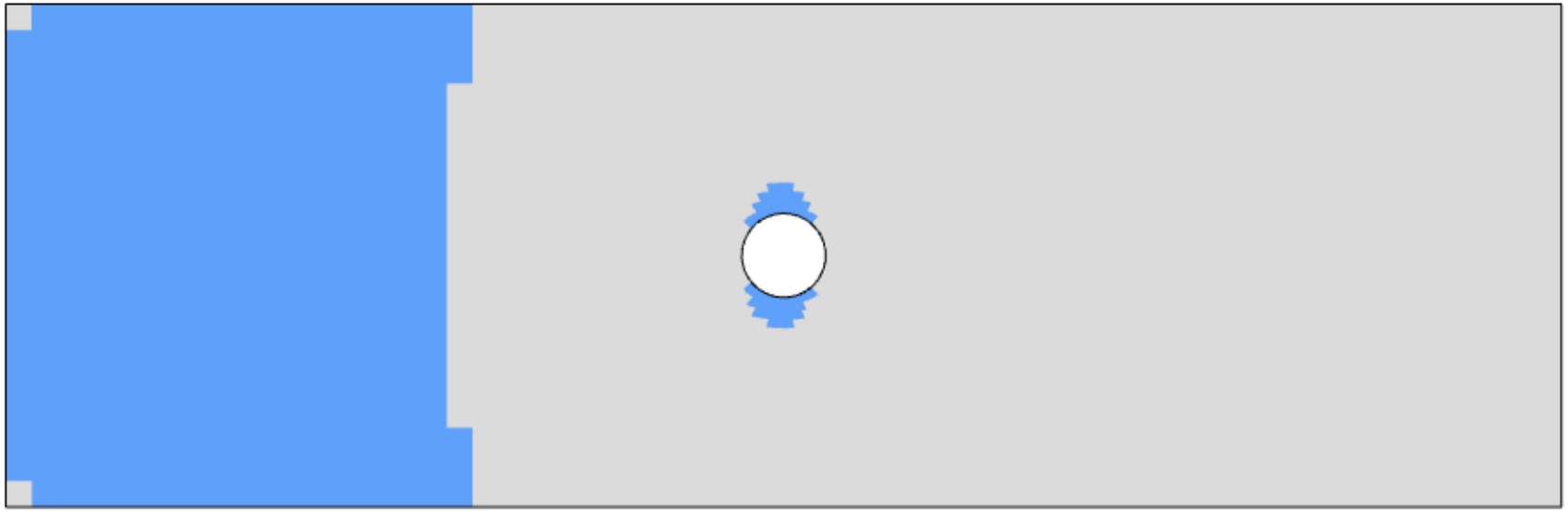
1

Ply Shape

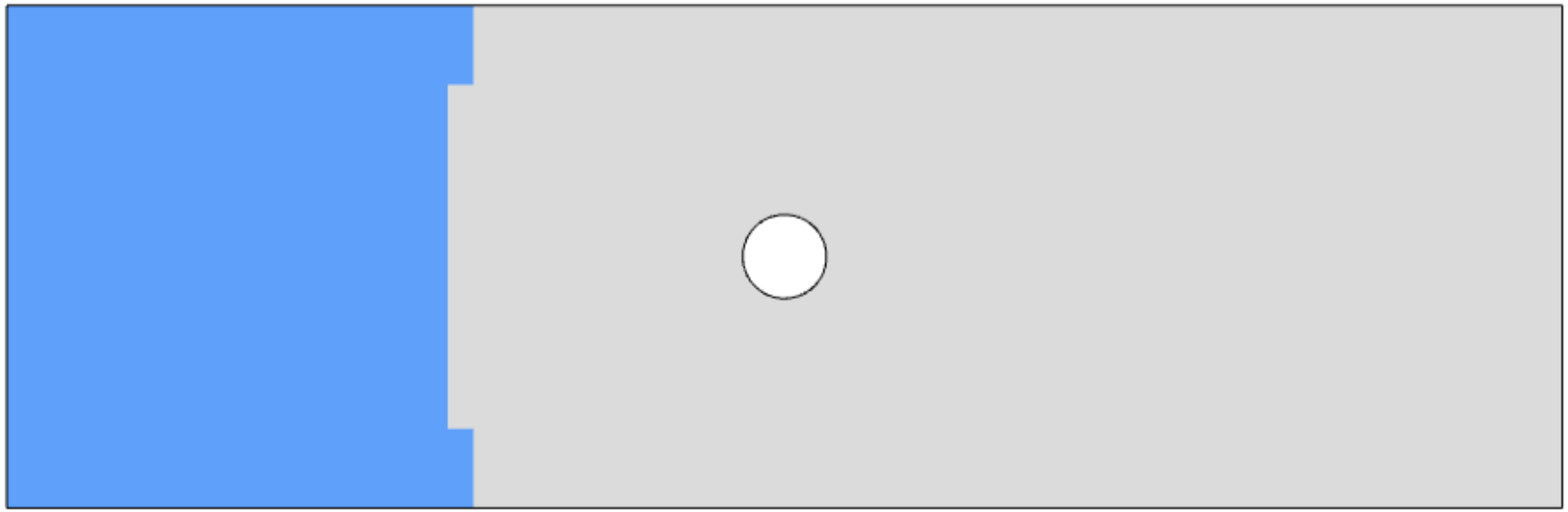
Layer, Theta	Ply Shape Candidate 1	Ply Shape Candidate 2	Ply Shape Candidate 3	Ply Shape Candidate 4	Ply Shape Candidate 5
5 90°	151000, 2151000	152000, 2152000	153000, 2153000		
6, 7 ±45°	161000, 2161000 171000, 2171000	162000, 2162000 172000, 2172000	163000, 2163000 173000, 2173000		
8 0°	181000, 2181000	182000, 2182000	183000, 2183000	184000, 2184000	185000, 2185000

Ply Shape Editing: Candidate 4 for 0°

Before



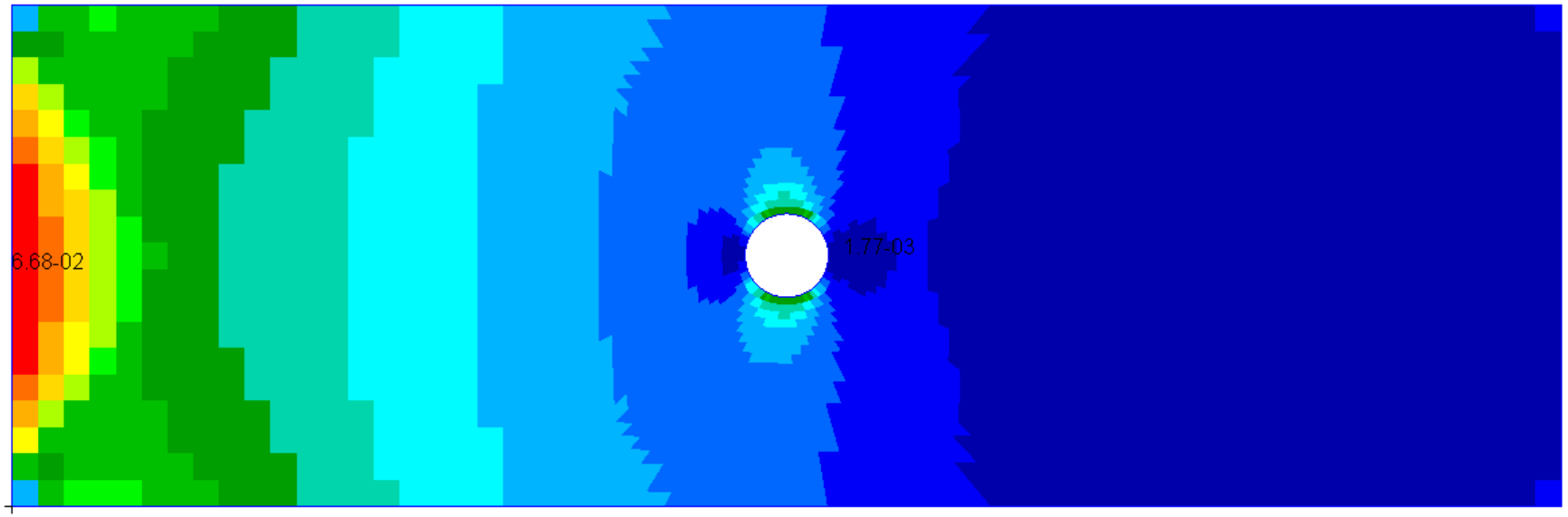
After



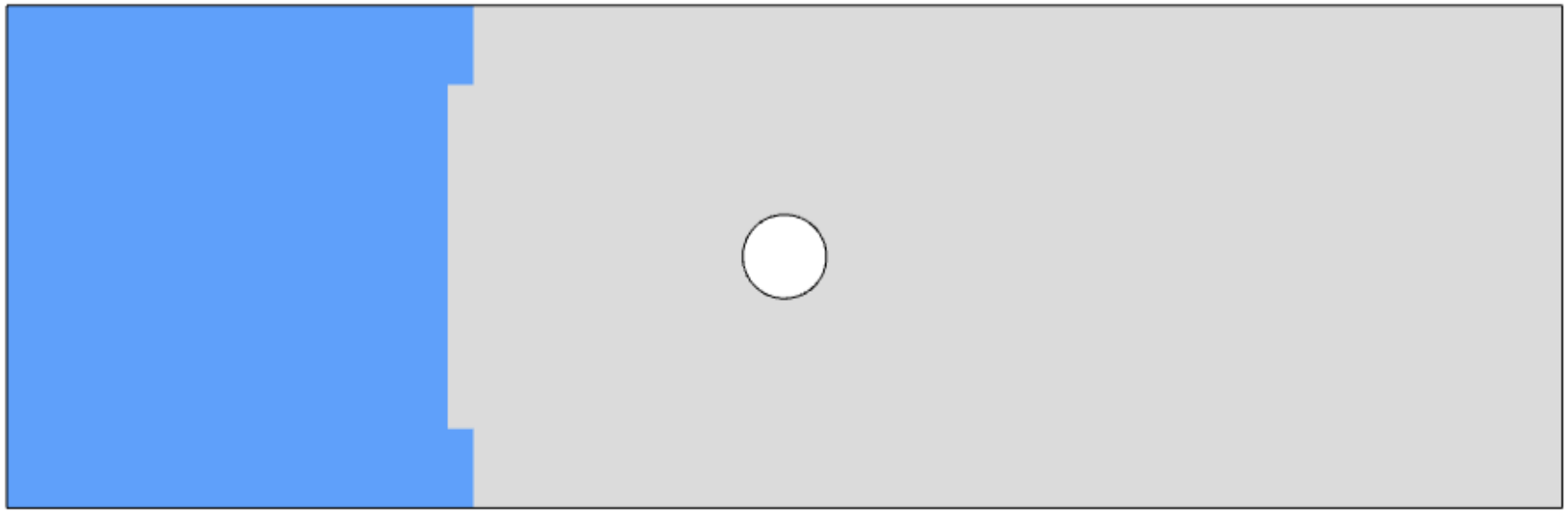
Ply Shape Editing: Candidate 4 for 0°

- The ply shape candidate takes a form that aligns with the contour of the maximum failure index plot
- The values used are the maximum failure indices of the 0° ply

Maximum Failure Index

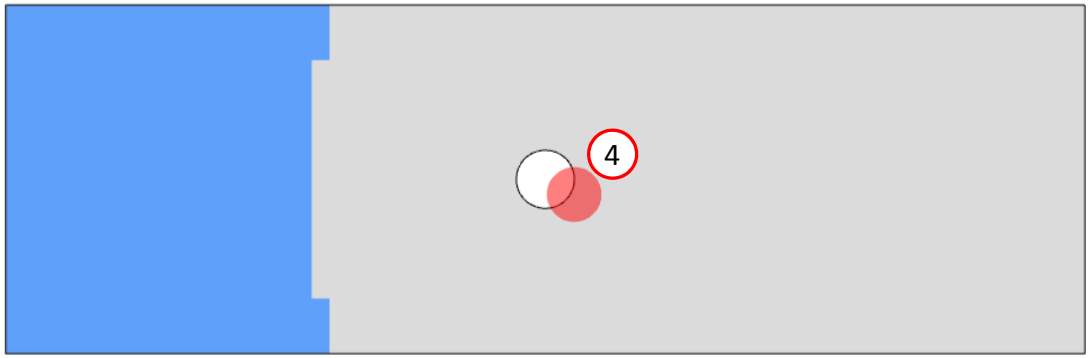


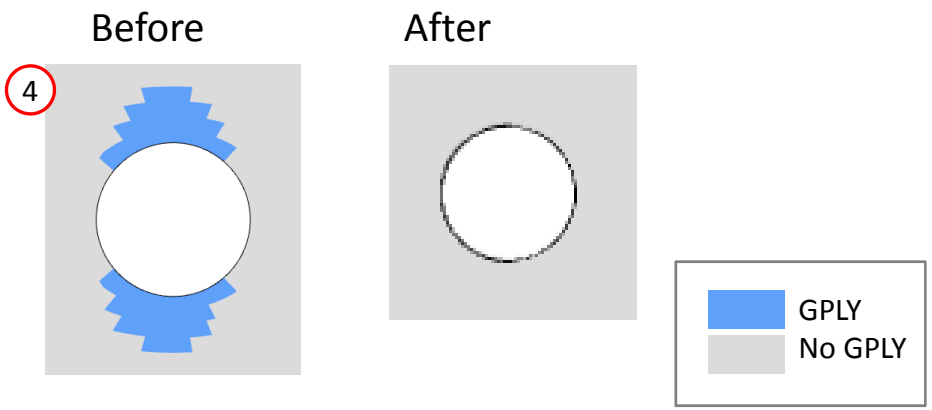
Ply Shape Candidate 2

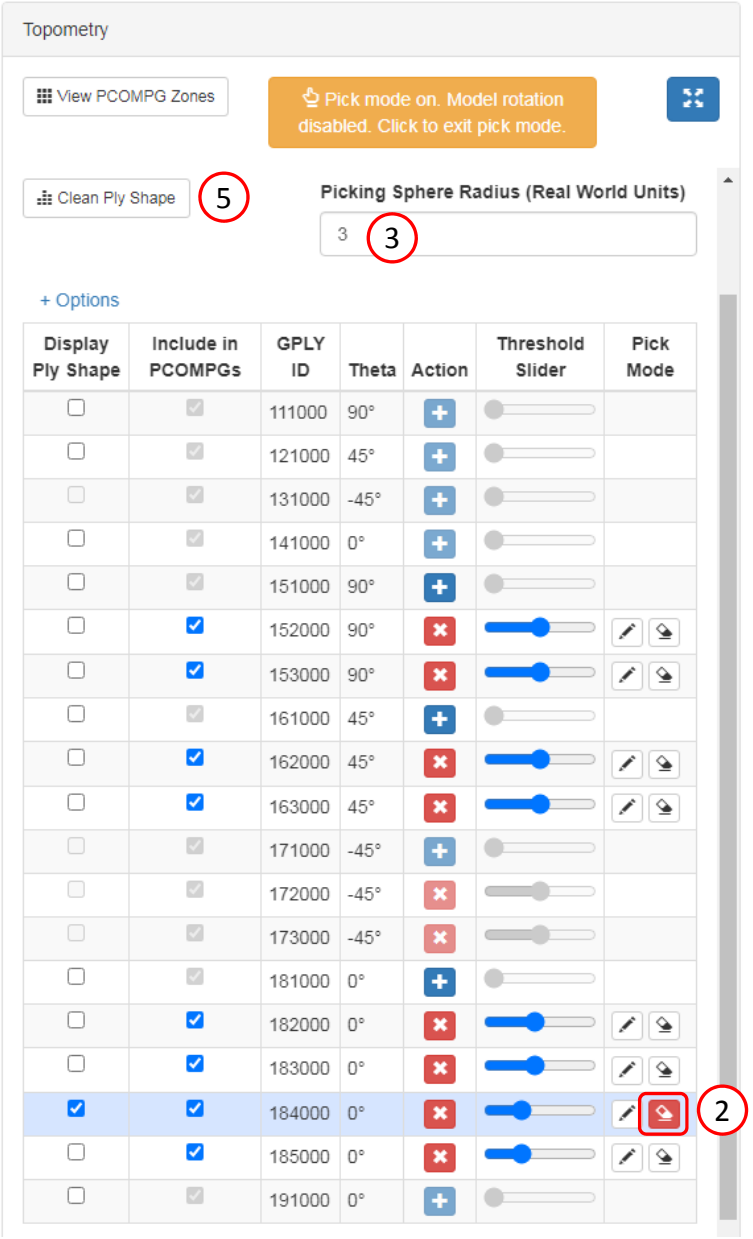


Ply Shape Editing: Candidate 4 for 0°

1. Click Fit Model to view the full model (not shown)
2. Click the indicated icon
3. A red sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to approximately 3 .
4. Press and hold the left mouse button, and drag the sphere to remove the ply from the indicated region.
5. Click Clean Ply Shape



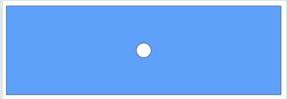
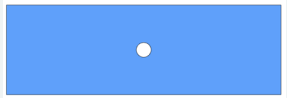
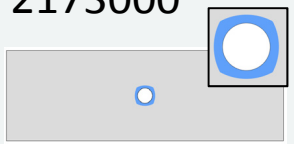
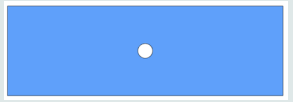




Ply Shape Candidates Creation

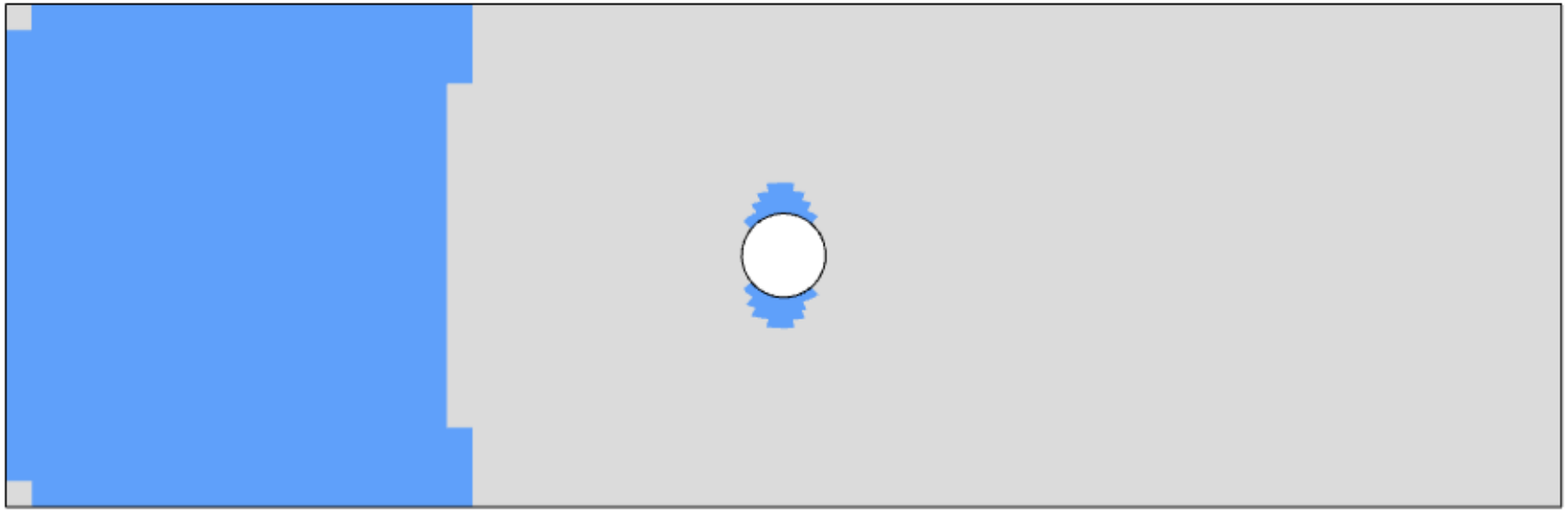
1. The indicated ply shape candidates will be created

Ply Shape

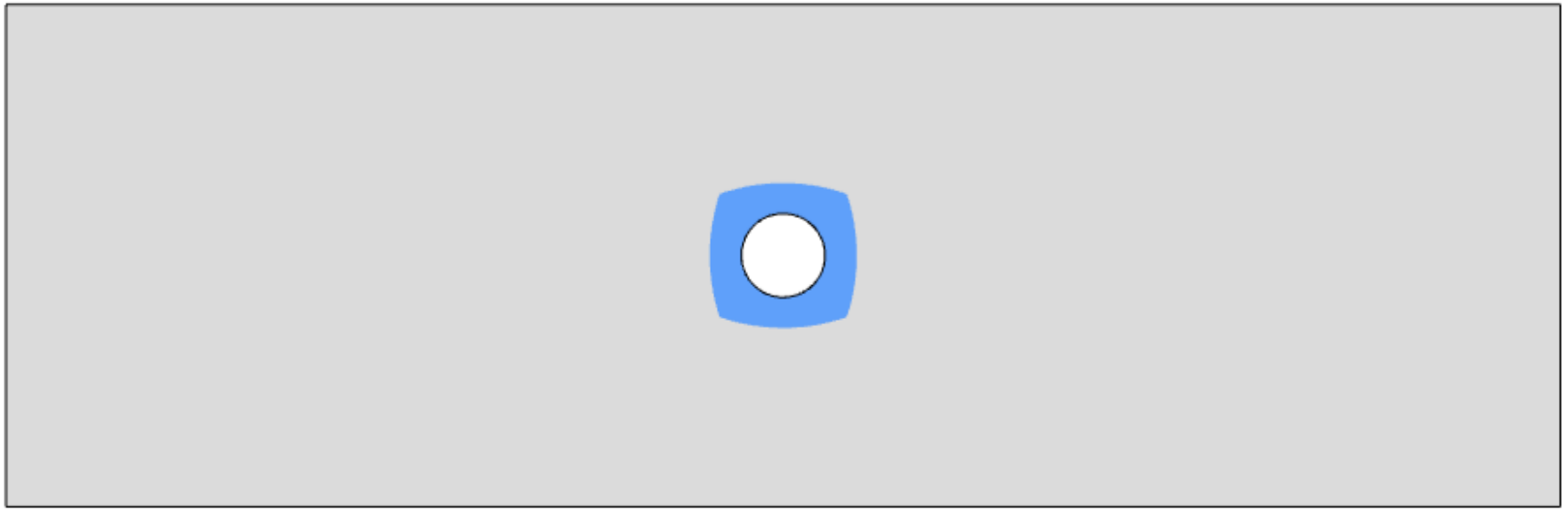
Layer, Theta	Ply Shape Candidate 1	Ply Shape Candidate 2	Ply Shape Candidate 3	Ply Shape Candidate 4	Ply Shape Candidate 5
5 90°	151000, 2151000 	152000, 2152000 	153000, 2153000 	1	
6, 7 ±45°	161000, 2161000 171000, 2171000 	162000, 2162000 172000, 2172000 	163000, 2163000 173000, 2173000 		
8 0°	181000, 2181000 	182000, 2182000 	183000, 2183000 	184000, 2184000 	185000, 2185000 

Ply Shape Editing: Candidate 5 for 0°

Before



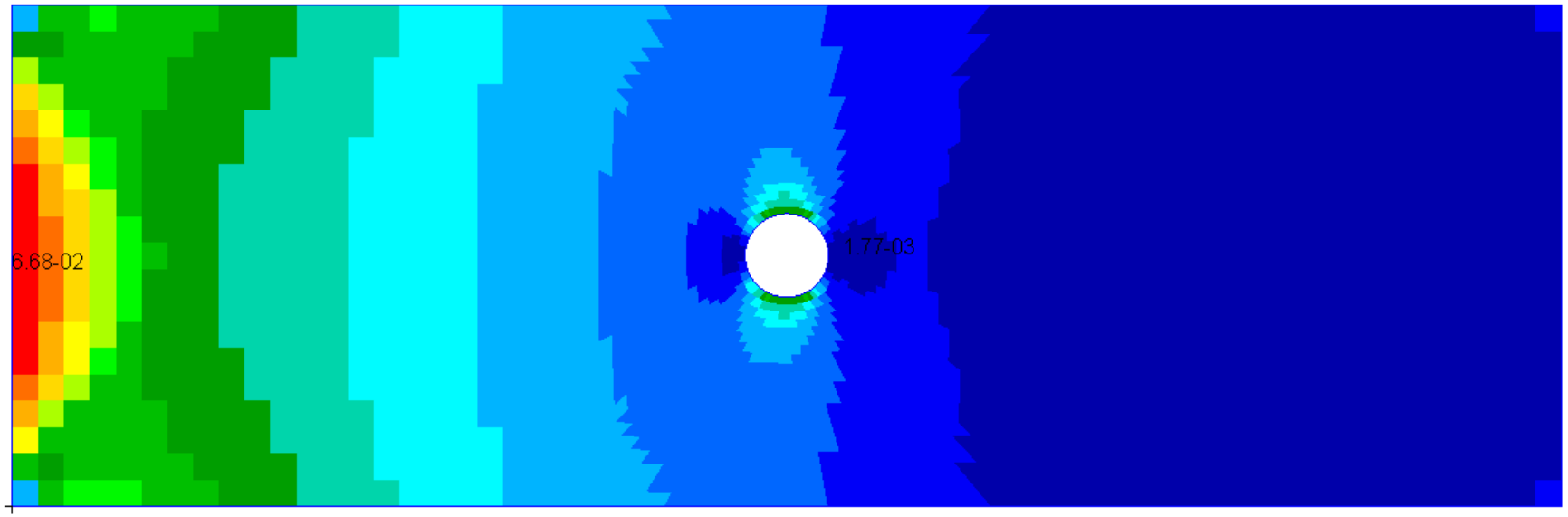
After



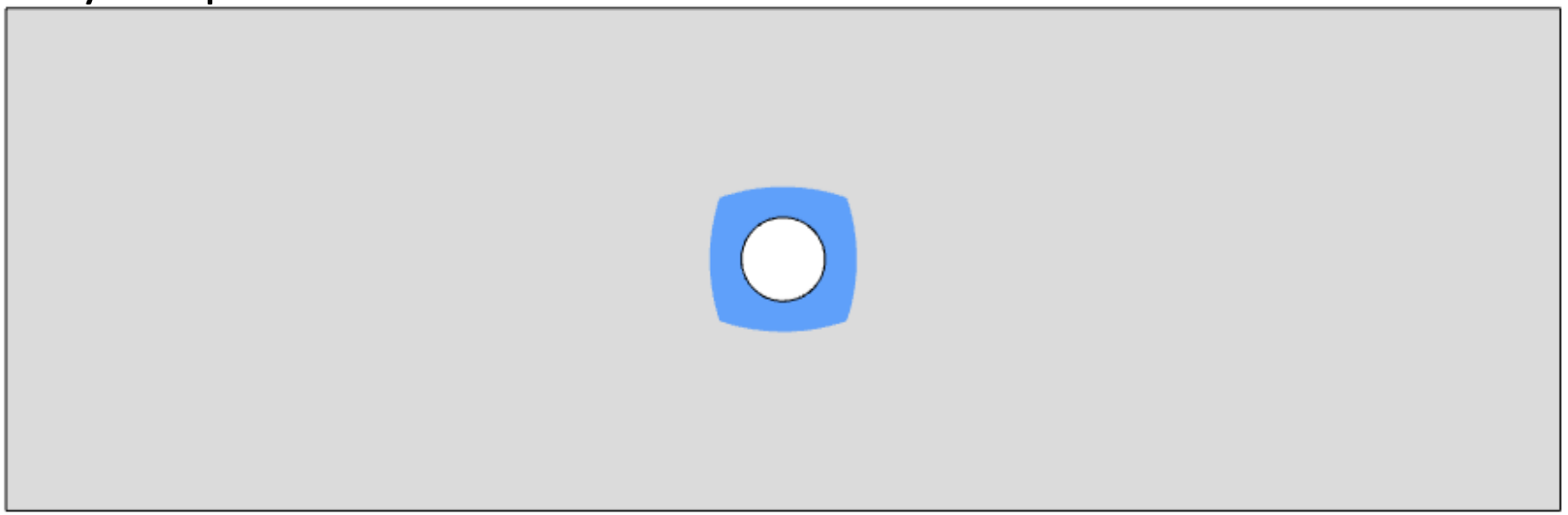
Ply Shape Editing: Candidate 5 for 0°

- The ply shape candidate takes a form that aligns with the contour of the maximum failure index plot
- The values used are the maximum failure indices of the 0° ply

Maximum Failure Index

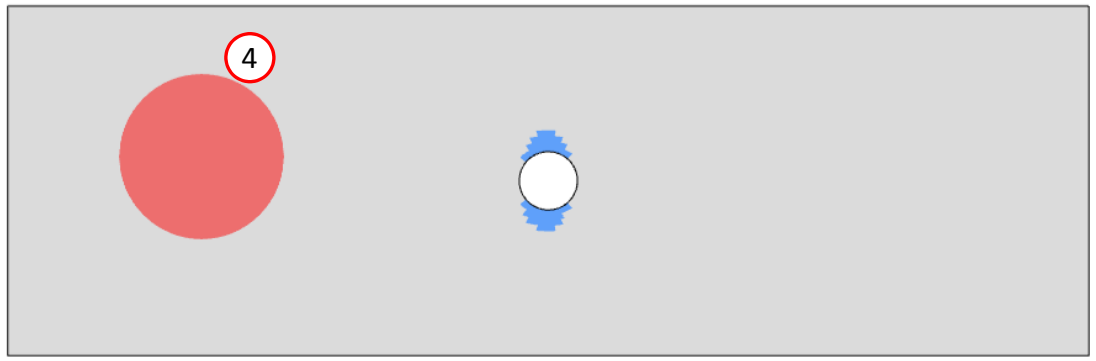


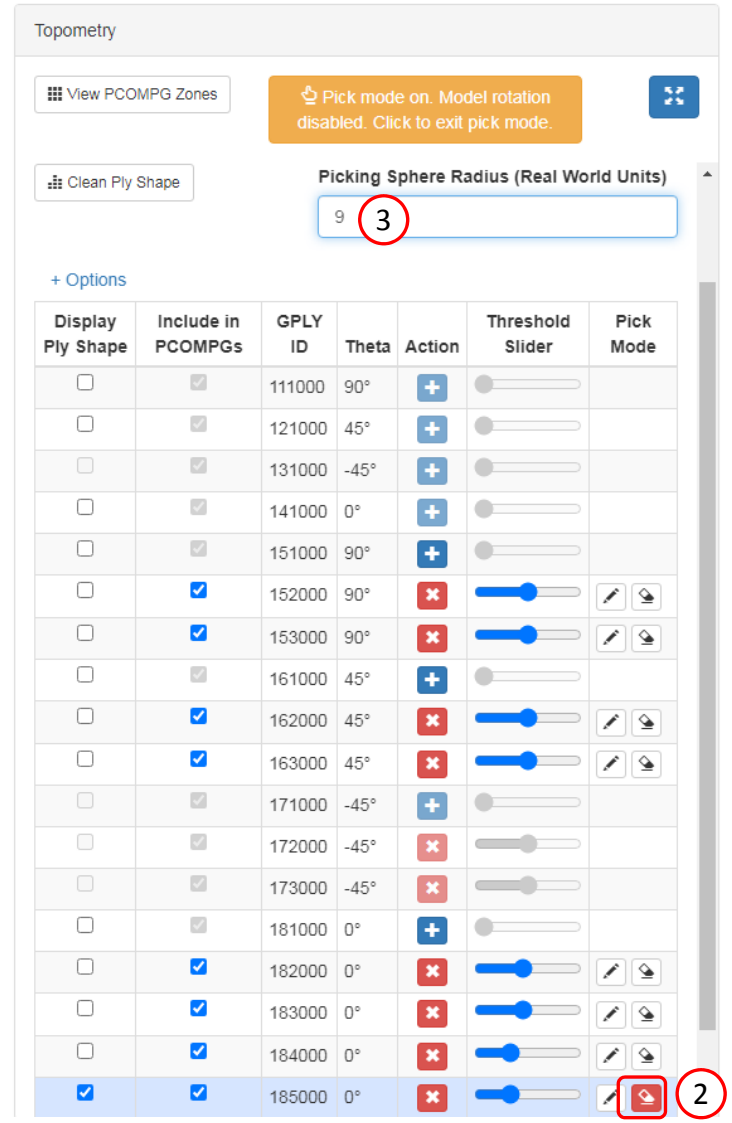
Ply Shape Candidate 2



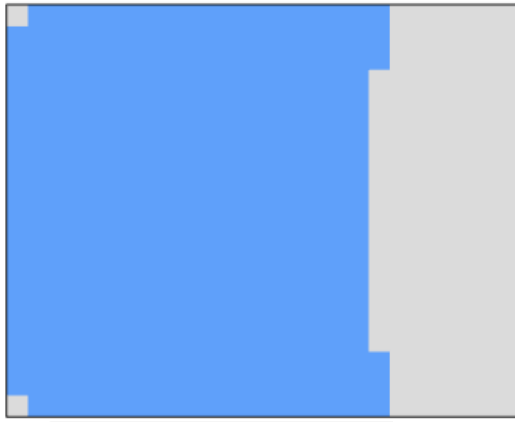
Ply Shape Editing: 0°, Candidate 5

1. Click Fit Model to view the full model (not shown)
2. Click the indicated icon
3. A red sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to approximately 9 .
4. Press and hold the left mouse button, and drag the sphere to remove the ply from the left side.

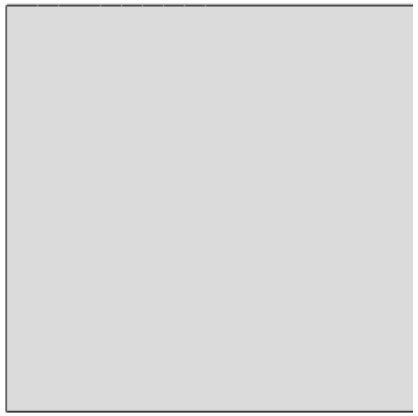


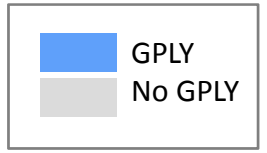


4 Before



After



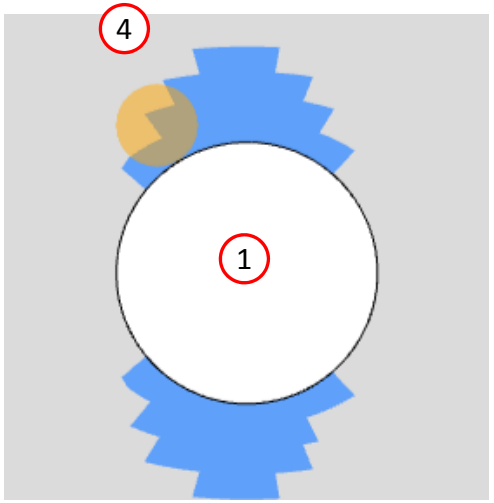


Ply Shape Editing: 0°, Candidate 5

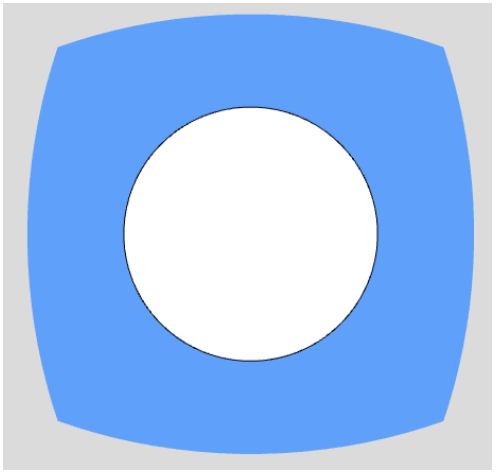
1. Use the scroll wheel on the mouse to zoom in to the hole
2. Click the indicated icon
3. A yellow sphere appears. The size of the sphere is adjusted. Set Picking Sphere Radius to 1 .
4. Press and hold the left mouse button, and drag the mouse to move the sphere and add the ply around the hole.

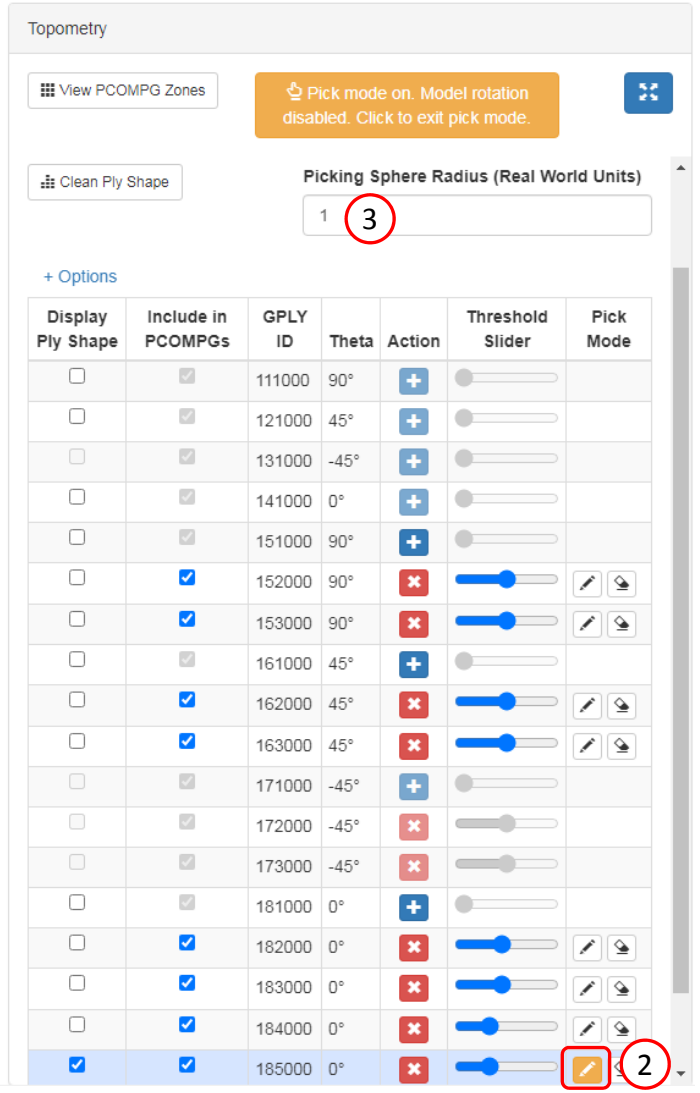
- If a ply shape is spread over the wrong element, use the erase option (red sphere) to remove the ply shape from unwanted regions.

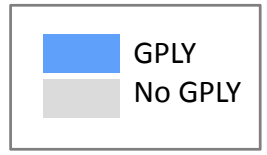
Before



After



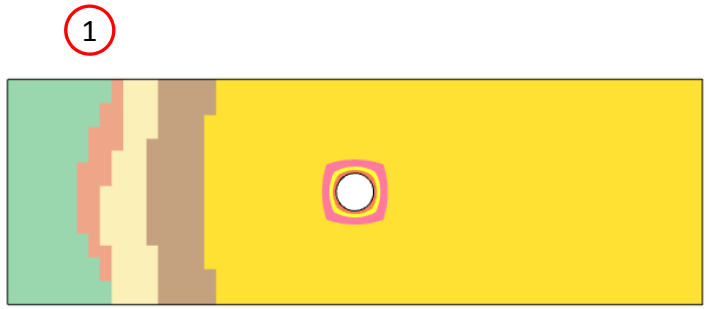


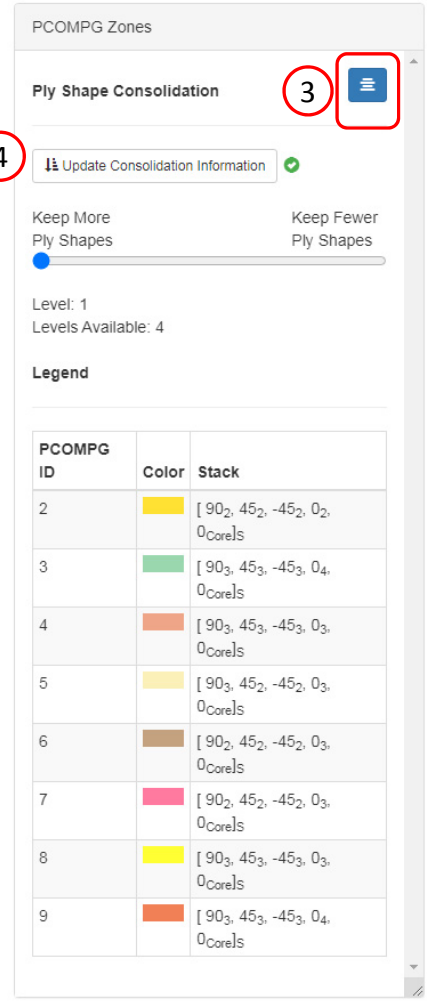


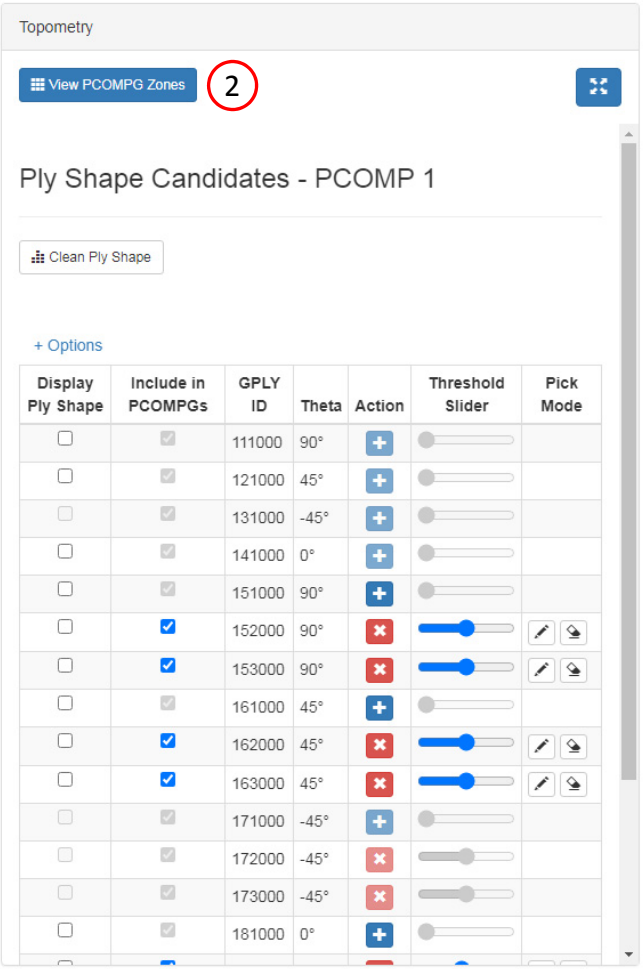
Ply Shape Consolidation

1. Use the mouse scroll wheel to zoom out
2. Click View PCOMPG Zones
3. Click the indicated icon to display the Ply Shape Consolidation section
4. Click Update Consolidation Information

- Refer to the appendix, section PCOMPG Zones, for more information regarding PCOMPG zones.

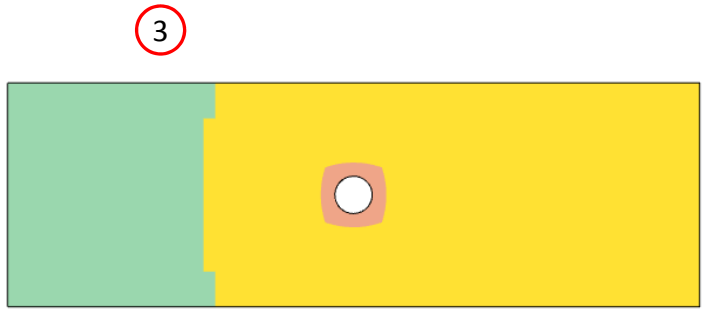


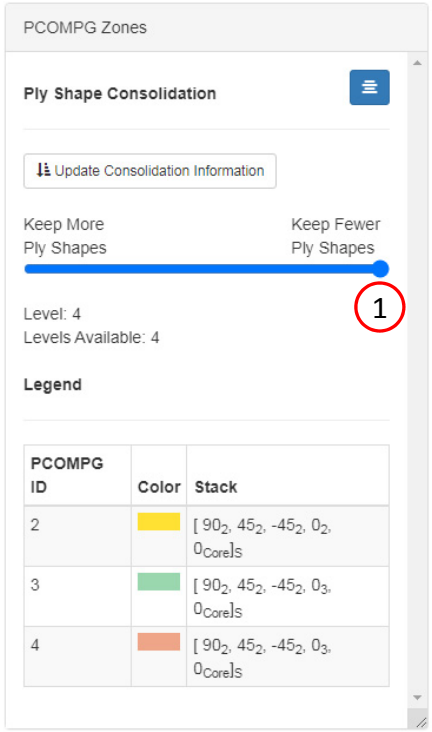


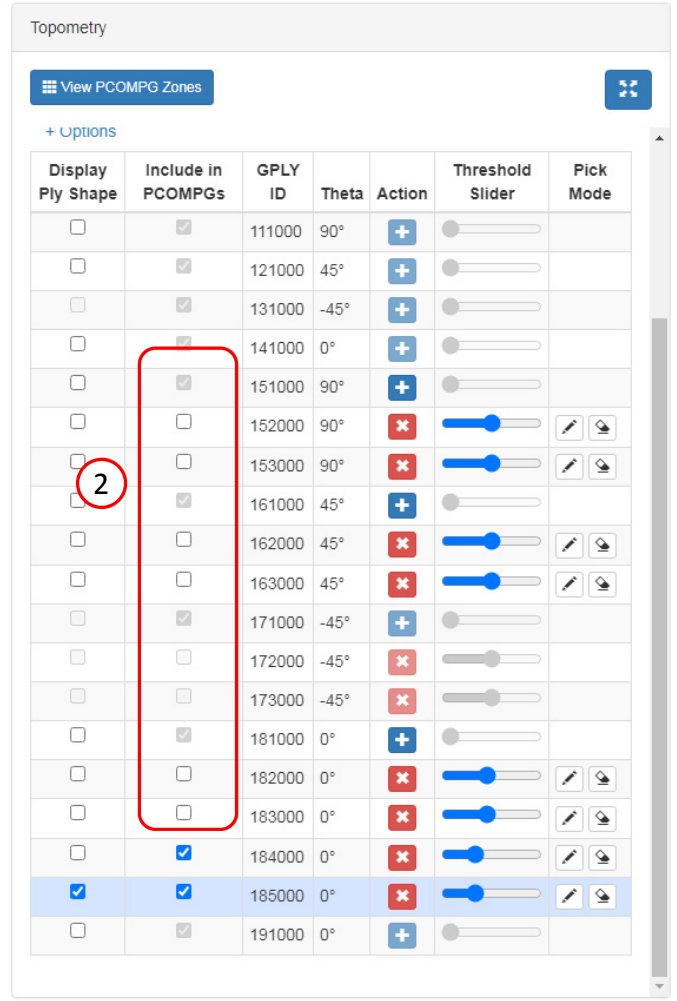


Ply Shape Consolidation

1. Move the slider to level 4
2. Note that the slider controls which checkboxes are marked. These checkboxes indicate which ply shapes are included in the final composite (PCOMPG entries).
3. The model is updated with different PCOMPG zones.

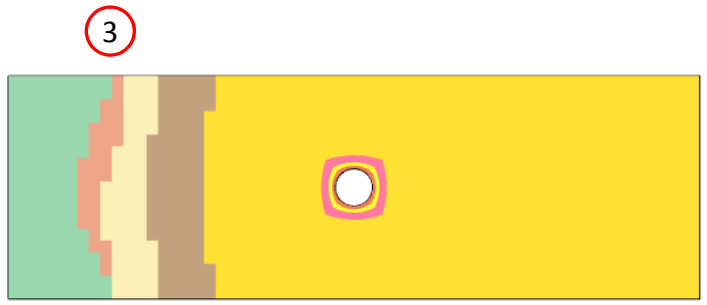






Ply Shape Consolidation

1. Move the slider back to level 1
2. Note all the checkboxes are marked and will be included in the final PCOMPG entries
3. Ensure the PCOMPG zones are similar to what is shown
4. Click the indicated icon



PCOMPG Zones

Ply Shape Consolidation

Update Consolidation Information

Keep More Ply Shapes — Keep Fewer Ply Shapes

1

Level: 1
Levels Available: 4

Legend

PCOMPG ID	Color	Stack
2		[90_2, 45_2, -45_2, 0_2, $0_{Core}]_S$
3		[90_3, 45_3, -45_3, 0_4, $0_{Core}]_S$
4		[90_3, 45_3, -45_3, 0_3, $0_{Core}]_S$
5		[90_3, 45_2, -45_2, 0_3, $0_{Core}]_S$
6		[90_2, 45_2, -45_2, 0_3, $0_{Core}]_S$
7		[90_2, 45_2, -45_2, 0_3, $0_{Core}]_S$
8		[90_3, 45_3, -45_3, 0_3, $0_{Core}]_S$
9		[90_3, 45_3, -45_3, 0_4, $0_{Core}]_S$

Topometry

View PCOMPG Zones

4

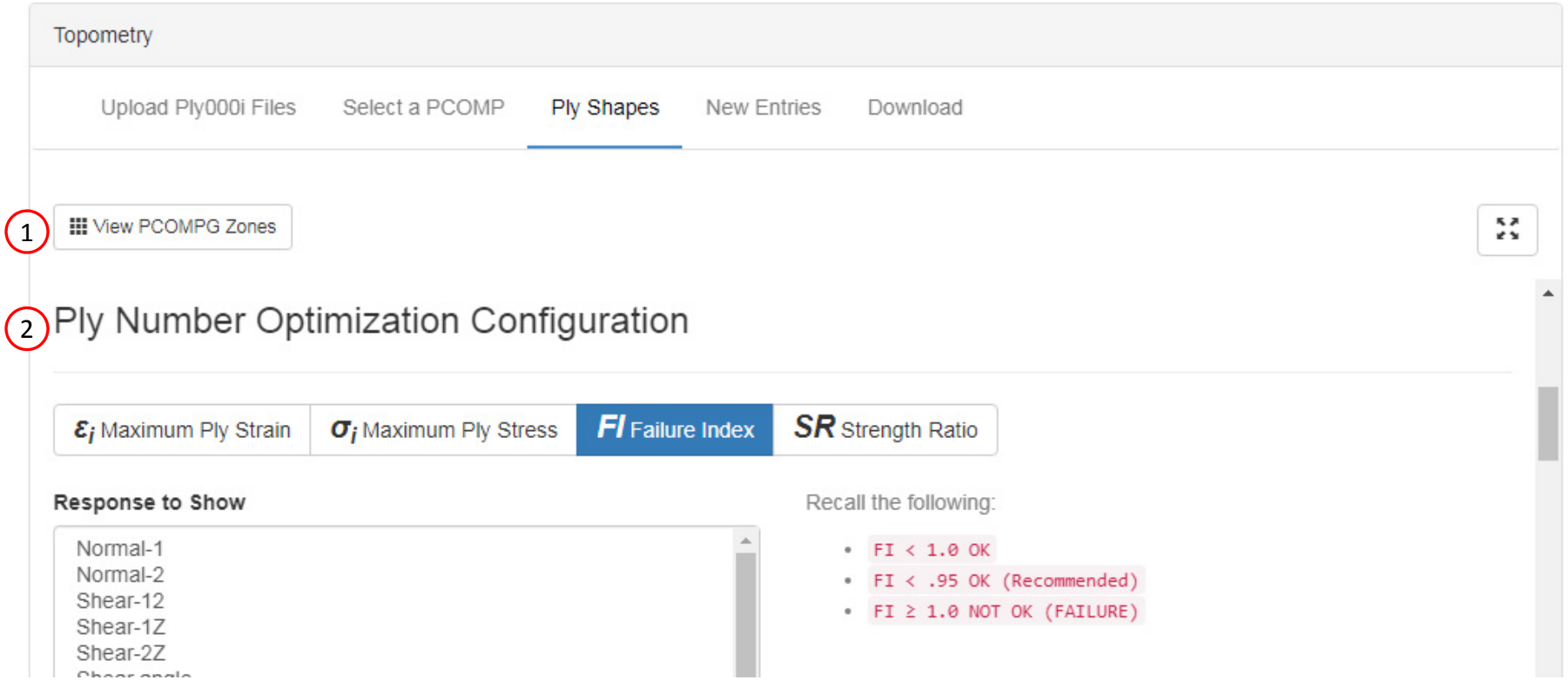
+ Options

Display Ply Shape	Include in PCOMPGs	GPLY ID	Theta	Action	Threshold Slider	Pick Mode
☐	☑	111000	90°	+		
☐	☑	121000	45°	+		
☐	☑	131000	-45°	+		
☐	☑	141000	0°	+		
☐	☑	151000	90°	+		
☐	☑	152000	90°	✖		
☐	☑	153000	90°	✖		
☐	☑	161000	45°	+		
☐	☑	162000	45°	✖		
☐	☑	163000	45°	✖		
☐	☑	171000	-45°	+		
☐	☑	172000	-45°	✖		
☐	☑	173000	-45°	✖		
☐	☑	181000	0°	+		
☐	☑	182000	0°	✖		
☐	☑	183000	0°	✖		
☐	☑	184000	0°	✖		
☑	☑	185000	0°	✖		
☐	☑	191000	0°	+		

2

Confirm Ply Number Optimization Configuration

1. Click View PCOMPG Zones to hide the PCOMPG Zones window
2. Navigate to section Ply Number Optimization Configuration



Confirm Ply Number Optimization Configuration

1. Ensure the ply thickness is blank for the outer plies
2. For the indicated rows, ensure the upper bound of the failure index is set to .95

GPLY ID	Theta	Candidate	Ply Thickness	Initial Number of Plies	Failure Index		
					Response	Lower Allowed Limit	Upper Allowed Limit
111000	90°	1	Thickness of Ply	.01	Failure Index(FP) for direct stresses/strains	Lower	.95
121000	45°	1	Thickness of Ply	.01	Failure Index(FP) for direct stresses/strains	Lower	.95
131000	-45°	1	Thickness of Ply	.01	Failure Index(FP) for direct stresses/strains	Lower	.95
141000	0°	1	Thickness of Ply	.01	Failure Index(FP) for direct stresses/strains	Lower	.95
151000	90°	1	.125	.01			

1

2

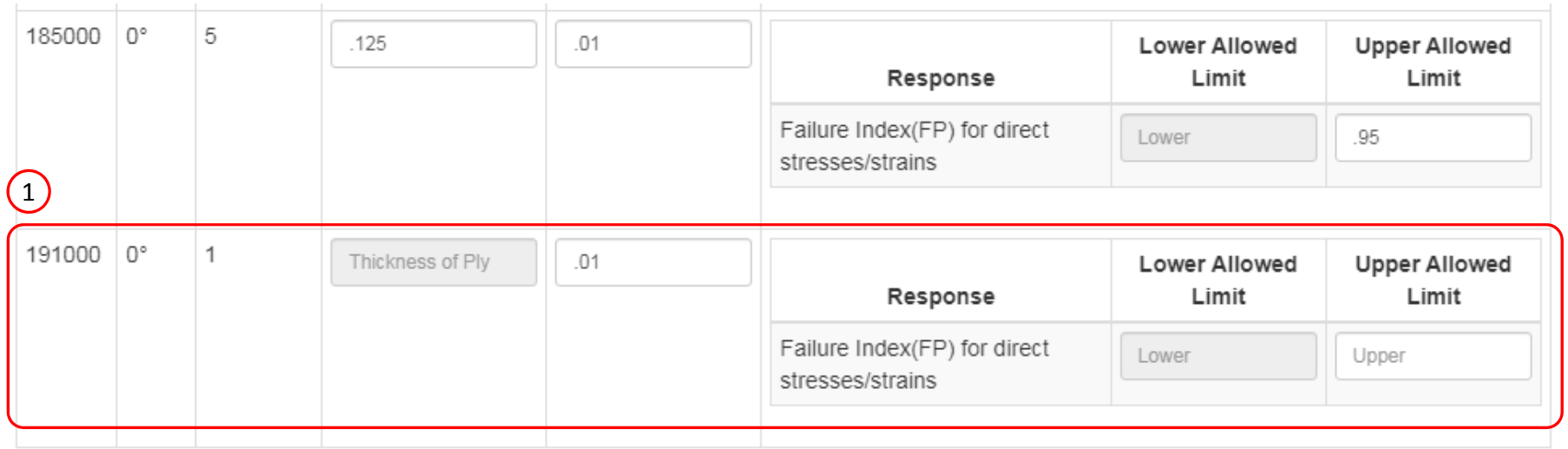
Confirm Ply Number Optimization Configuration

Do the following for ply shape candidates with GPLY ID: 151000, 152000, 153000, 161000, 162000, 163000, 171000, 172000, 173000, 181000, 182000, 183000, 184000, 185000 (rows 5-18 of the table)

1. For the indicated rows, ensure the ply thickness is set to .125 mm
2. For the indicated rows, ensure the upper bound of the failure index is set to .95
3. The ply thickness is not necessary for the -45° layers because the -45° layers are linked to the +45° layers (not shown). During the ply number optimization, one ply number variable controls the +45° and -45° plies.

Confirm Ply Number Optimization Configuration

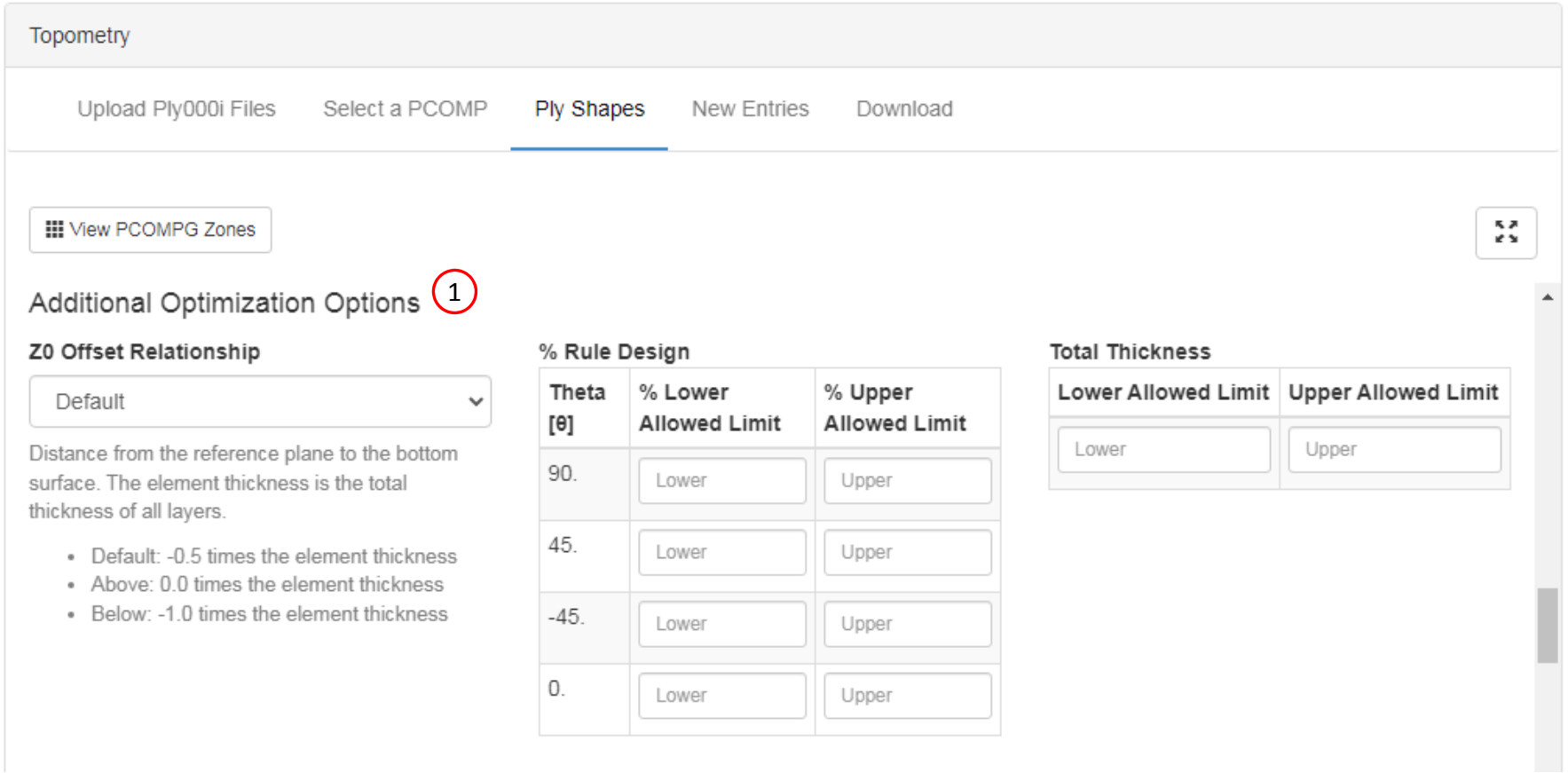
1. Recall the core is neither optimized, nor constrained. The input boxes for the core are left blank.



Consider Additional Optimization Options

1. Scroll to section Additional Optimization Options. There are additional options to adjust the ply number optimization.

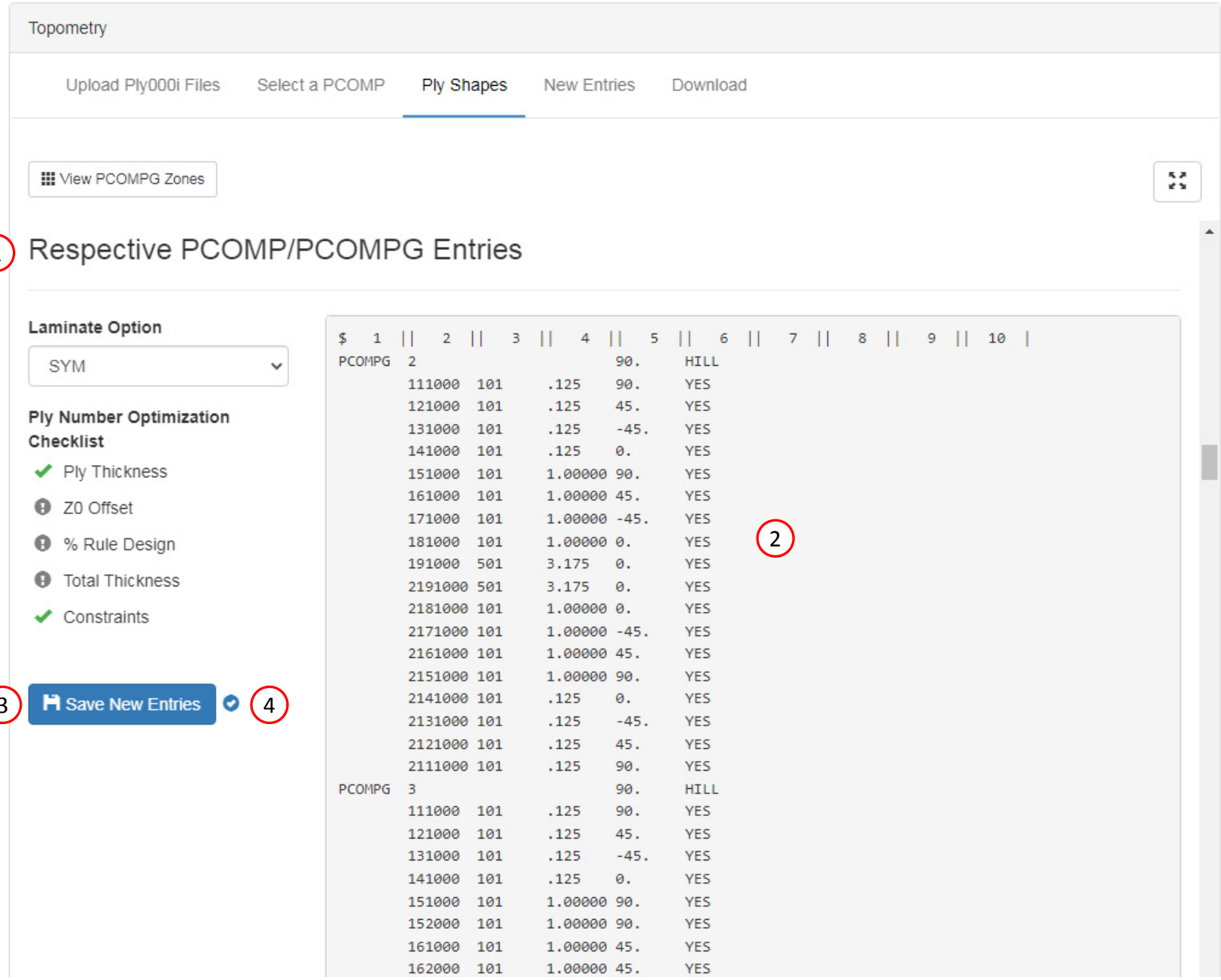
Refer to the appendix for more information about these options.



Save New Entries

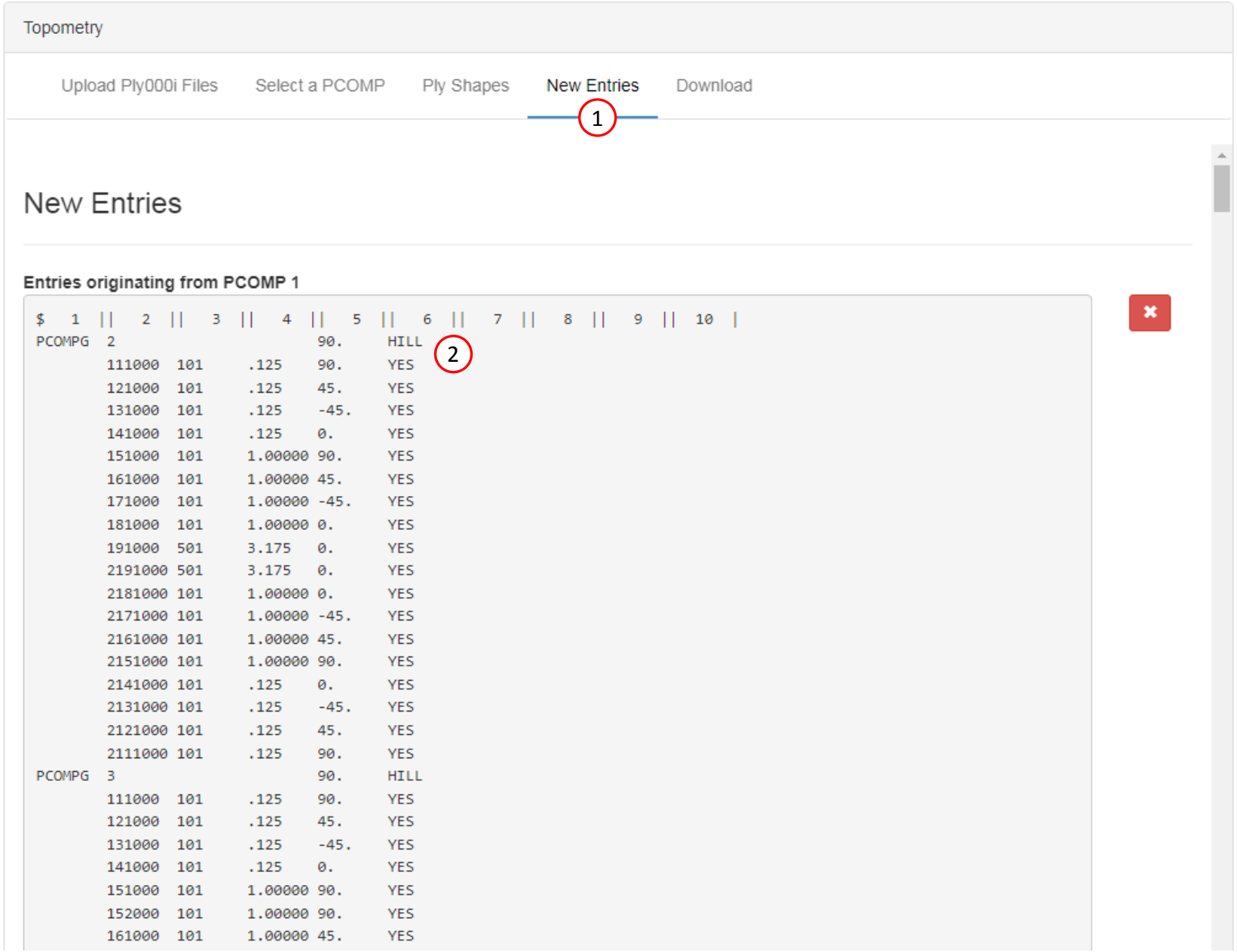
1. Navigate to section Respective PCOMP/PCOMPG Entries
2. The newest entries are displayed. There are approximately 8 new PCOMPG entries (PCOMPG 2-9) and multiple SOL 200 entries (DESVAR, DVPREL1, etc.)
3. Click Save New Entries
4. A checkbox confirm the entries has been saved.

Always be sure to click Save New Entries to commit any changes to the final downloaded BDF files.



Save New Entries

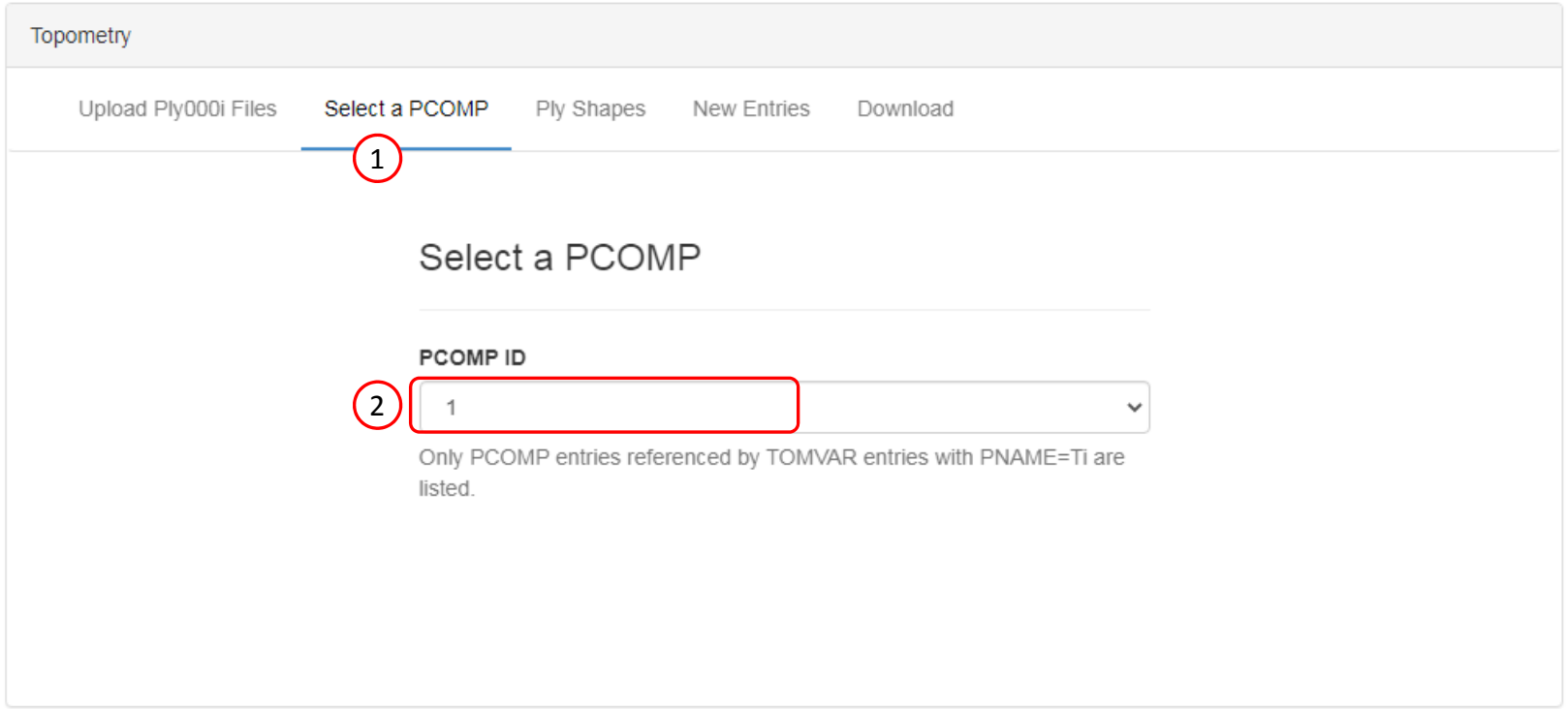
1. Click New Entries
2. All the newest bulk data entries are displayed. These entries will be added to the downloaded BDF files.



Consideration for Multiple PCOMPs

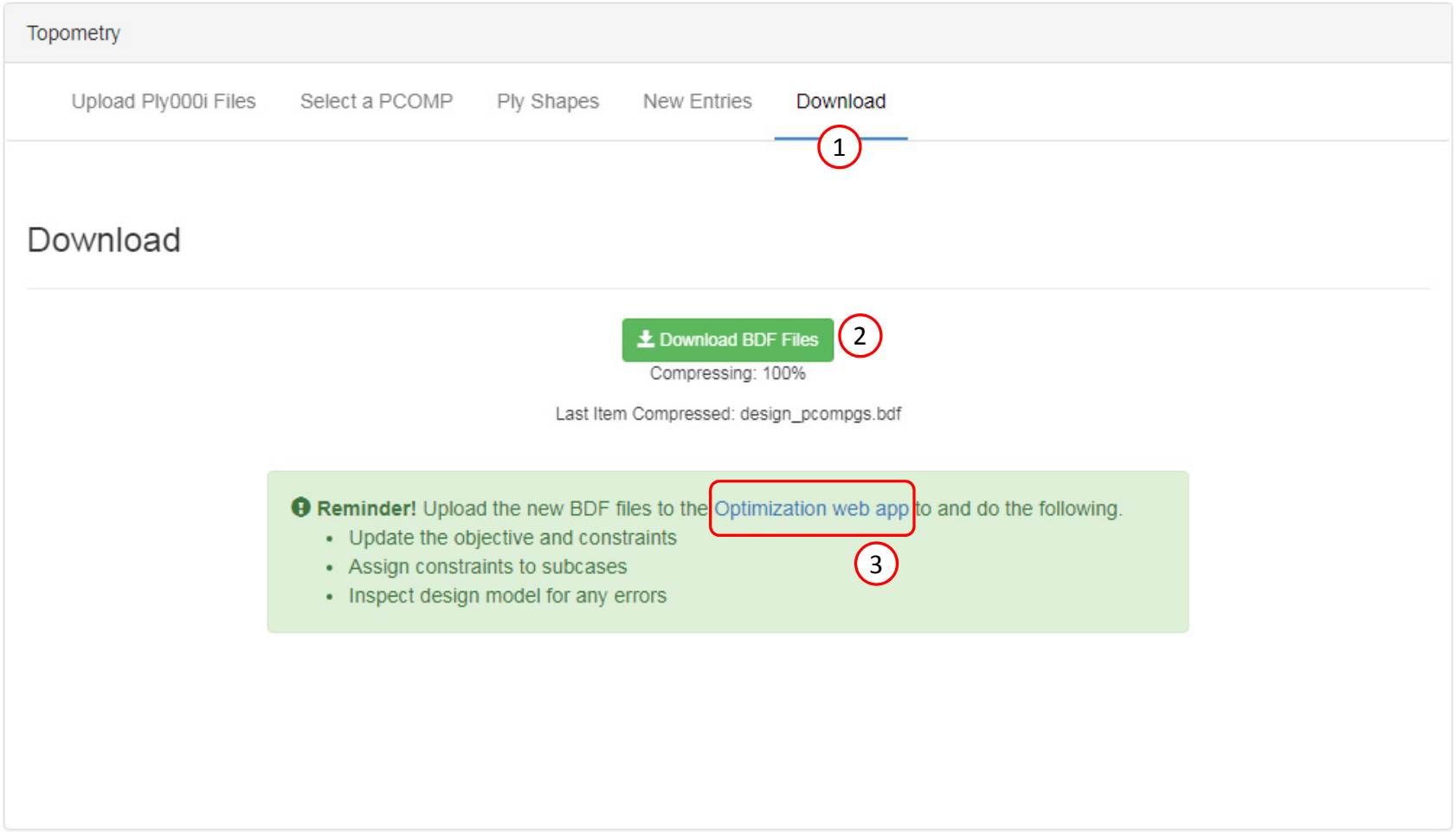
1. Click Select a PCOMP
2. If TOMVAR entries were defined for multiple PCOMP entries, ply shapes may be defined for each PCOMP. Use the Select a PCOMP section to switch between the different PCOMPs.

- Optimal ply shapes may be constructed for other layers in different PCOMPs as long as the following conditions are met.
    1. A TOMVAR entry is created for that layer
    2. A PLY000i file is created for that layer



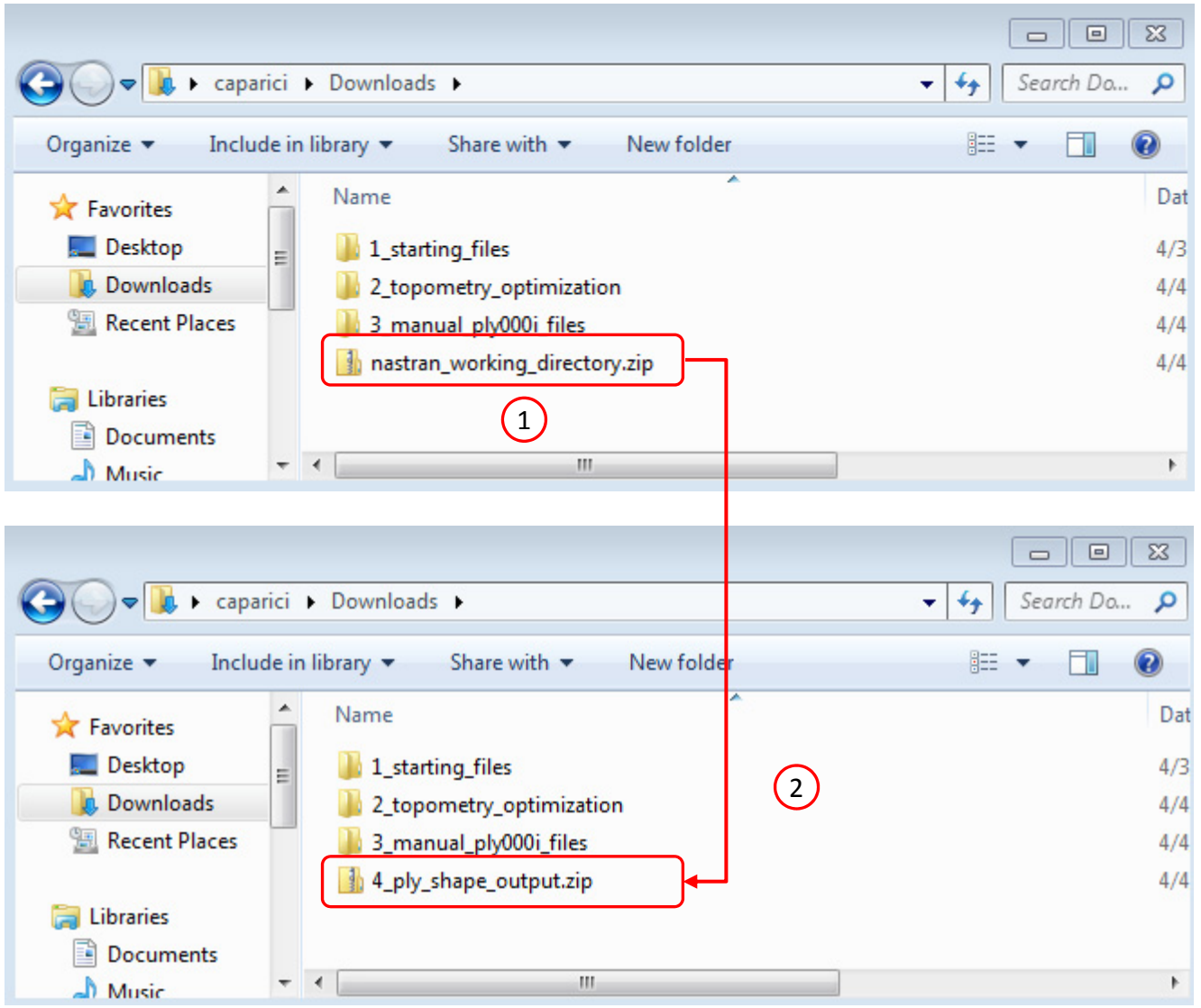
Download

1. Click Download
2. Click Download BDF Files
3. A reminder is displayed. The downloaded BDF files require additional configuration. Click the indicated link to open the Optimization web app.



Rename ZIP File

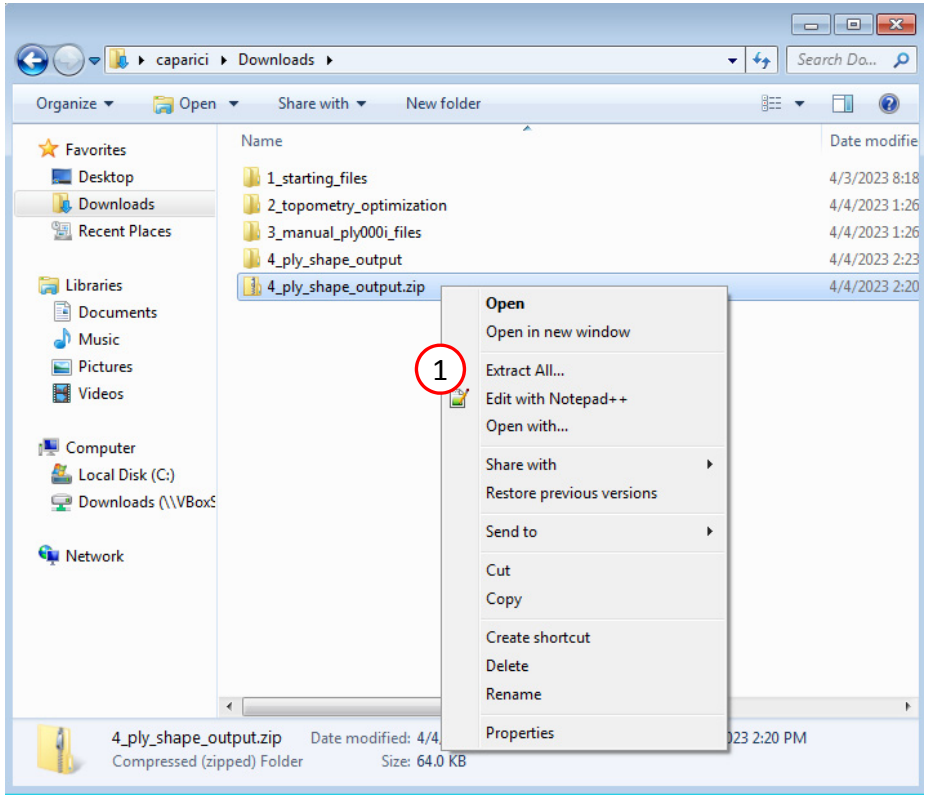
1. A new ZIP file has been downloaded
2. Rename the downloaded ZIP file to 4_ply_shape_output.zip

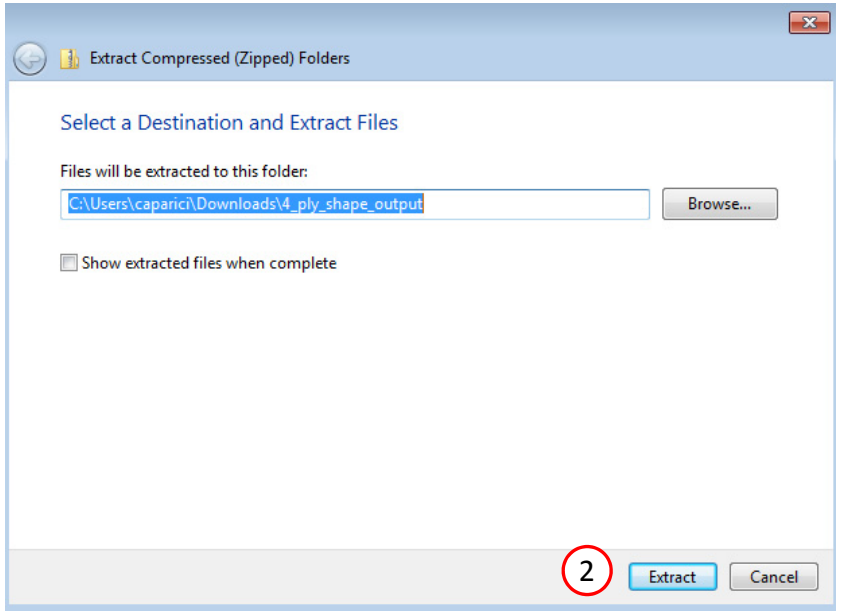


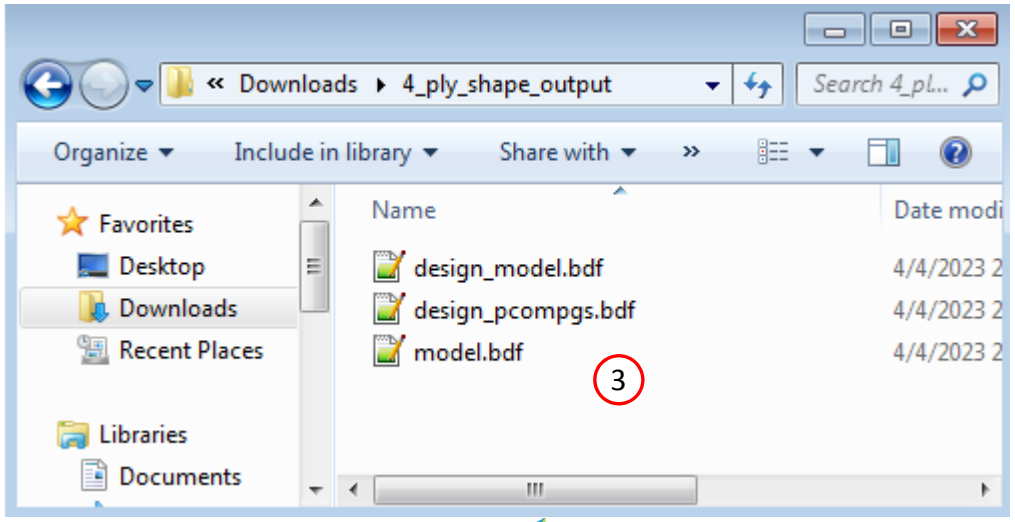
Part 2 – Ply Number Optimization

Extract the ZIP File

1. Right click on the ZIP file and click Extract All
2. Click Extract
3. A new folder with the new BDF files has been created

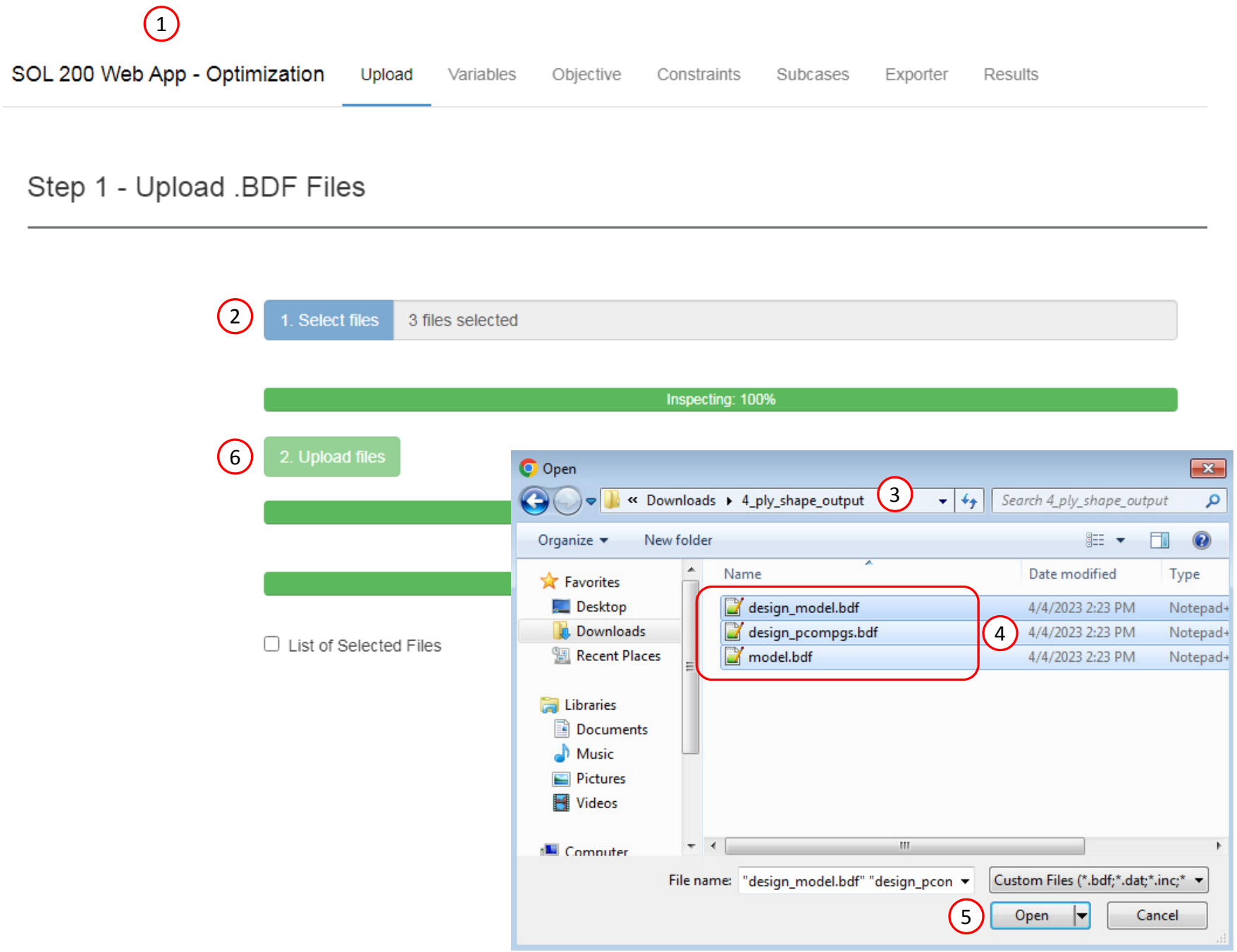






Upload BDF Files

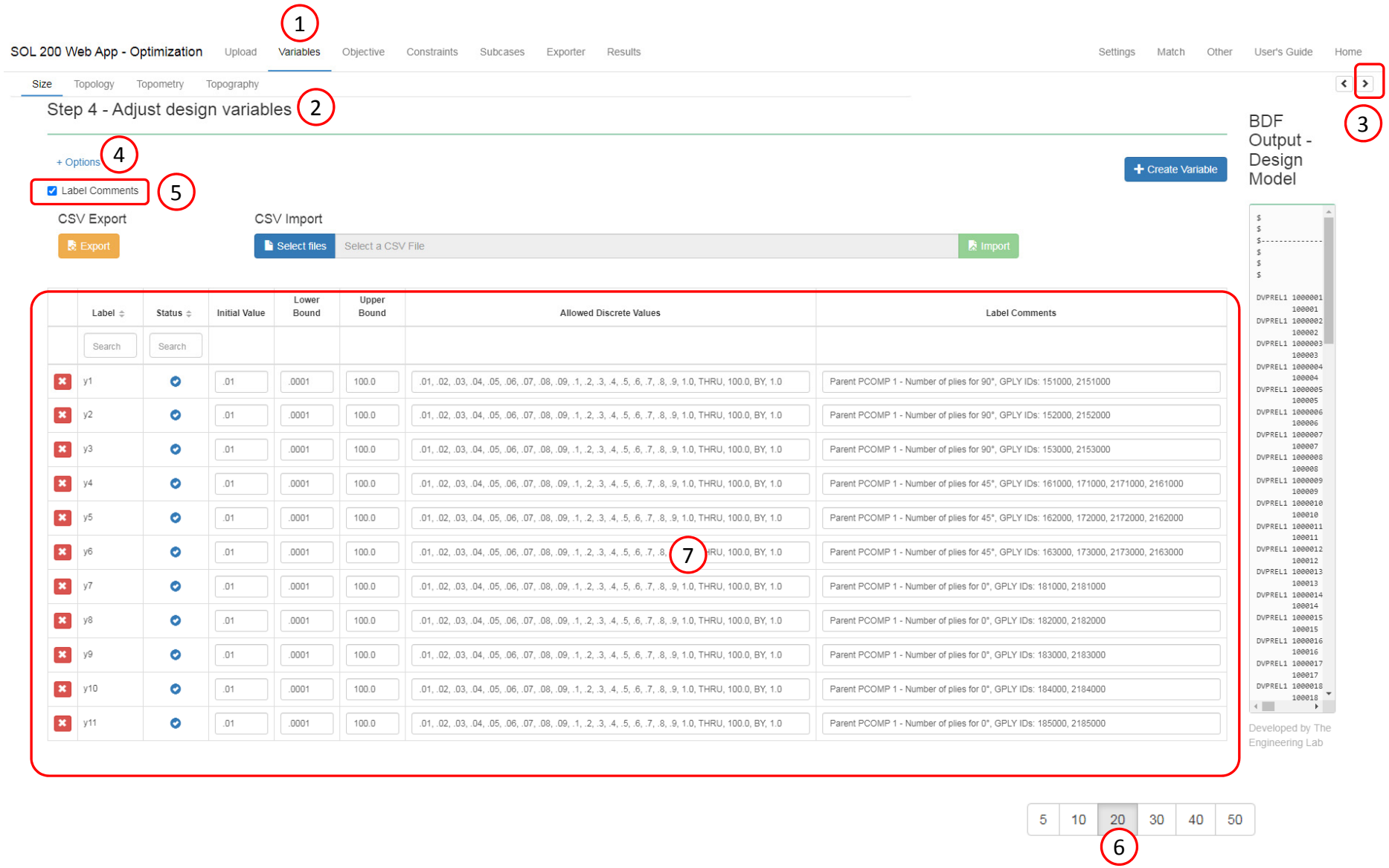
1. Switch to the Optimization web app
2. Click Select files
3. Navigate to directory 4_ply_shape_output
4. Select the indicated files
5. Click Open
6. Click Upload files



Variables

1. Click Variables
2. Navigate to section Step 4 – Adjust design variables
3. Click the indicated icon 3 times to expand the width of the variables section
4. Click +Options
5. Mark the checkbox for Label Comments
6. Click 20 to display at most 20 rows in the table
7. All the ply number variables are displayed

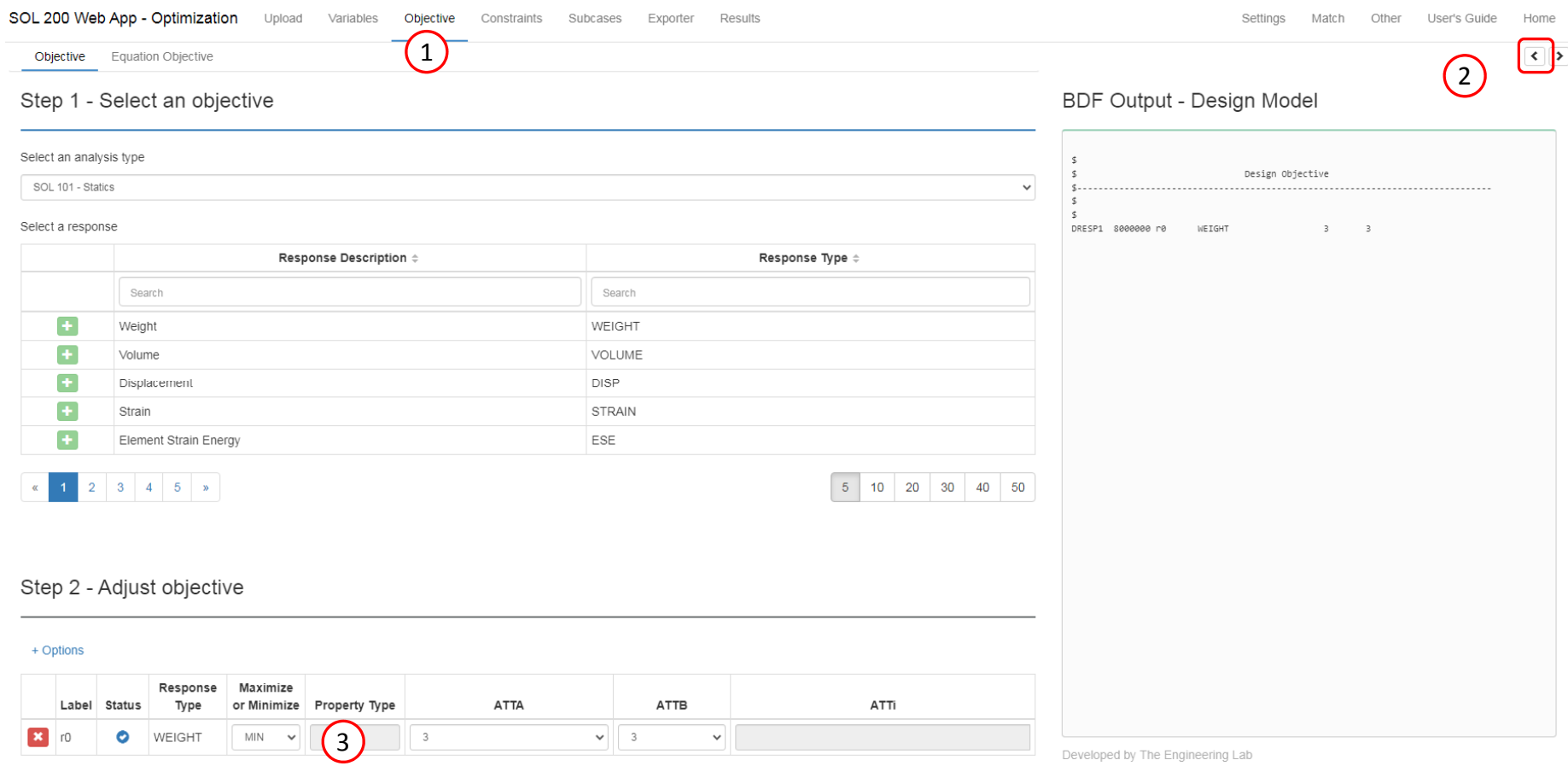
- When defining new ply shapes in the Viewer web app, a ply thickness was defined. By providing ply thickness values, ply number variables have been automatically created. On this page, those ply number variables are inspected.
- From experience, it has been found that if the initial number of plies is high, e.g. 60, 50 or 40 plies, the optimization converges to a sub-optimal solution. If the initial number of plies starts at a very fractional values, e.g. 0.01 plies, the converged solution is more optimal.
- The ply number variables (y1, y2, …, y11) will take on discrete values of 1, 2, 3, 4, etc. Also, small fractional values are purposely used to determine negligible plies.



Objective

1. Click Objective
2. Click the indicated icon 3 times to minimize the width of the objective section
3. The weight is already set as an objective

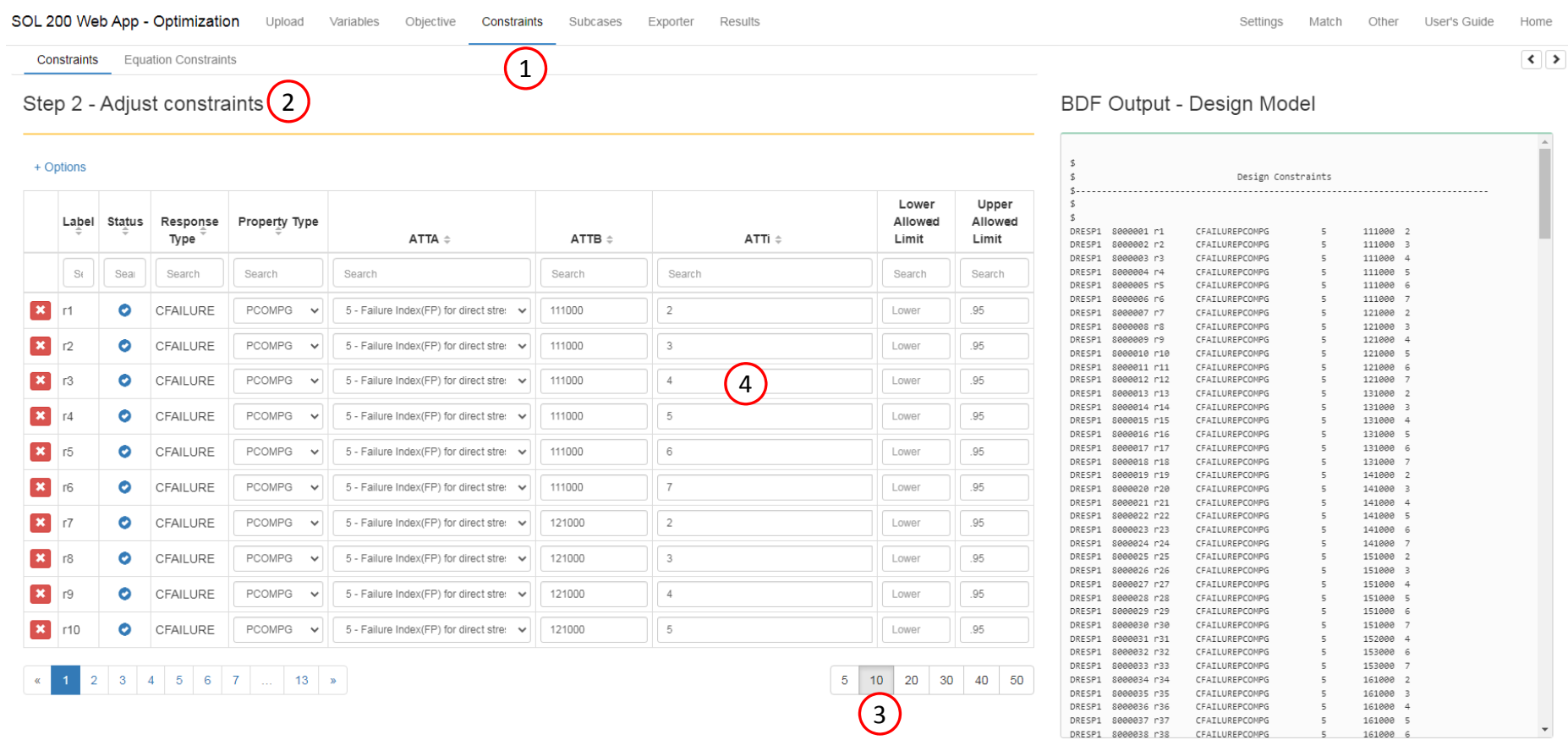
- The objective was previously defined in the BDF files when the TOMVAR entries were defined. The weight objective is left as is.



Constraints

1. Click Constraints
2. Navigate to section Step 2 – Adjust constraints
3. Click 10 to display at most 10 rows in the table
4. The design constraints on failure index are displayed

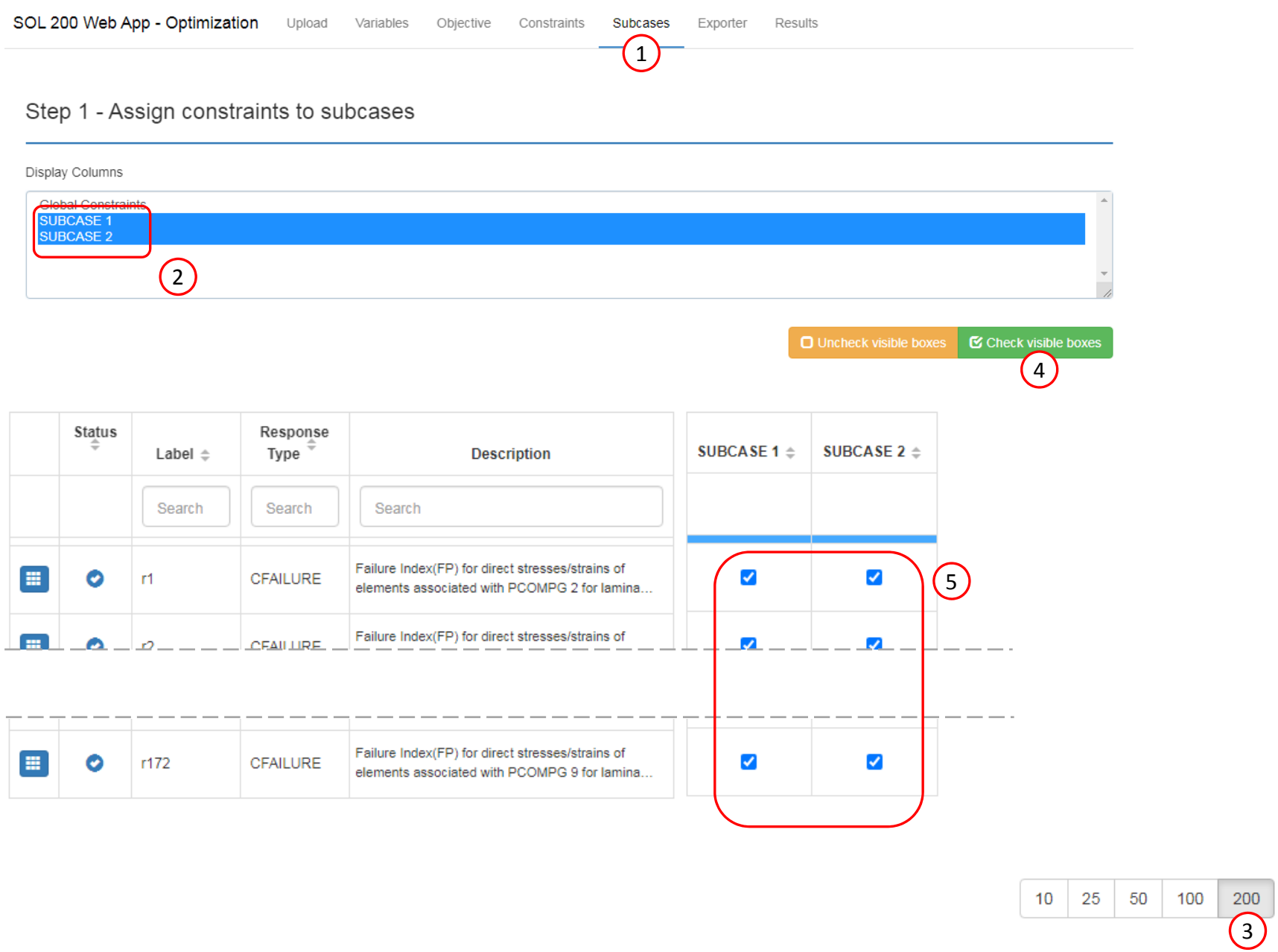
- When defining new ply shapes in the Viewer web app, an upper bound on the failure indices was specified and corresponding DRESP1/DCONSTR entries were created. These design constraints are inspected on this page.



Subcases

1. Click Subcases
2. Select only SUBCASE 1 and 2
3. Click 200 to display at most 200 rows in the table
4. Click Check visible boxes
5. All the failure index constraints have been assigned to subcase 1 and 2.

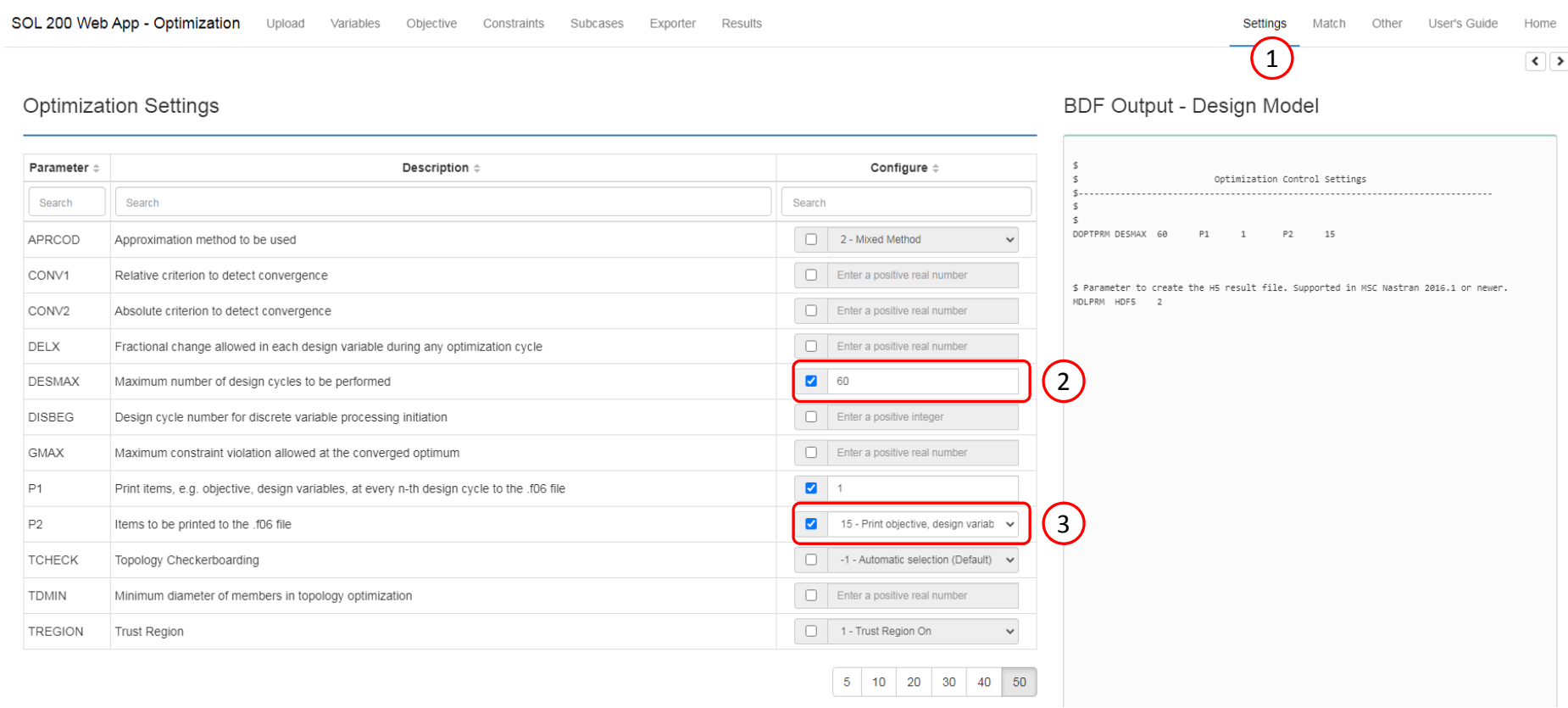
- The Viewer web app automatically created ply number variables and constraints on the failure indices. The optimization web app is used to assigned the constraints to different subcases, as shown on this page.



Settings

1. Click Settings
2. Set the maximum number of design cycles to 60
3. Set P2 to 15 – Print objective, design variables, …

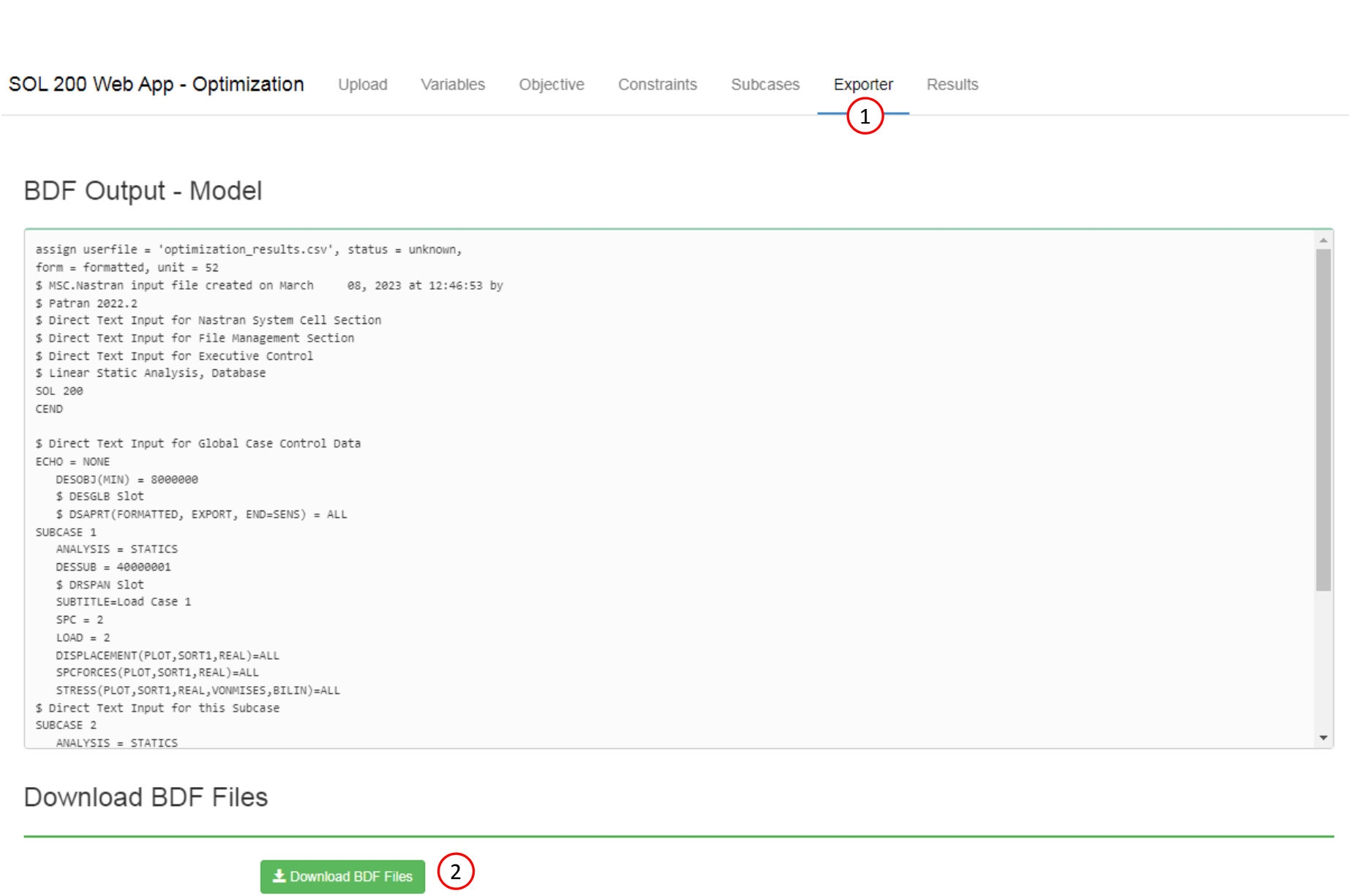
- The P2 option is used for debugging optimizations. If a topometry optimization is performed, a P2 setting equal to 15 will yield a lot of variable information in the F06 file. When defining the original BDF files with TOMVAR entries, P2 was automatically set to 12, so as to leave out variable information from the F06 file. On this page, the P2 option is set back to 15 which will include the design variable information in the F06 file.



Export New BDF Files

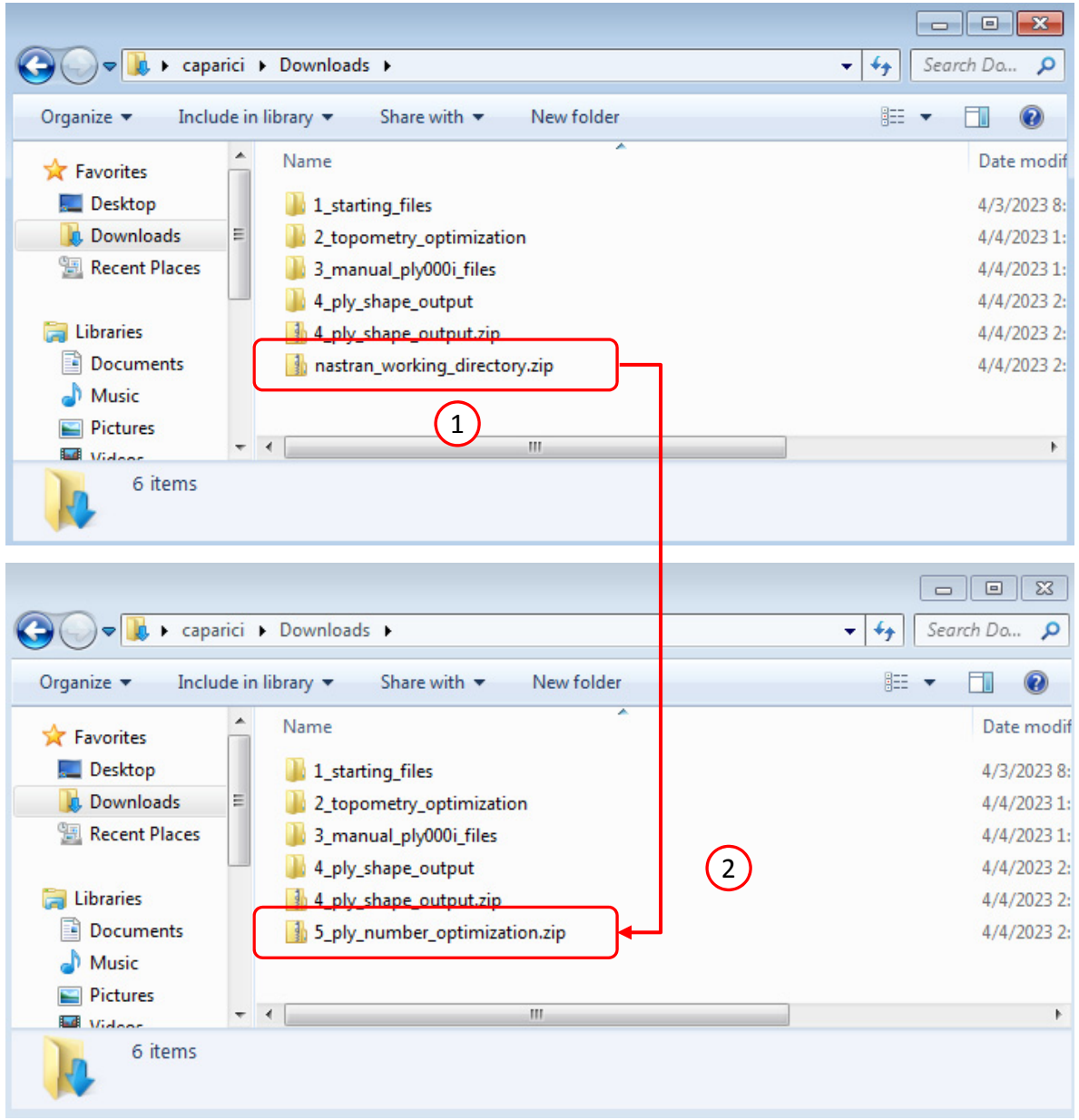
1. Click on Exporter
2. Click on Download BDF Files

- When the download button is clicked a new file named “nastran_working_directory” is downloaded. If the file already exists in your local folder, the folder name is appended with a number, e.g. “nastran_working_directory (1).zip”



Rename ZIP File

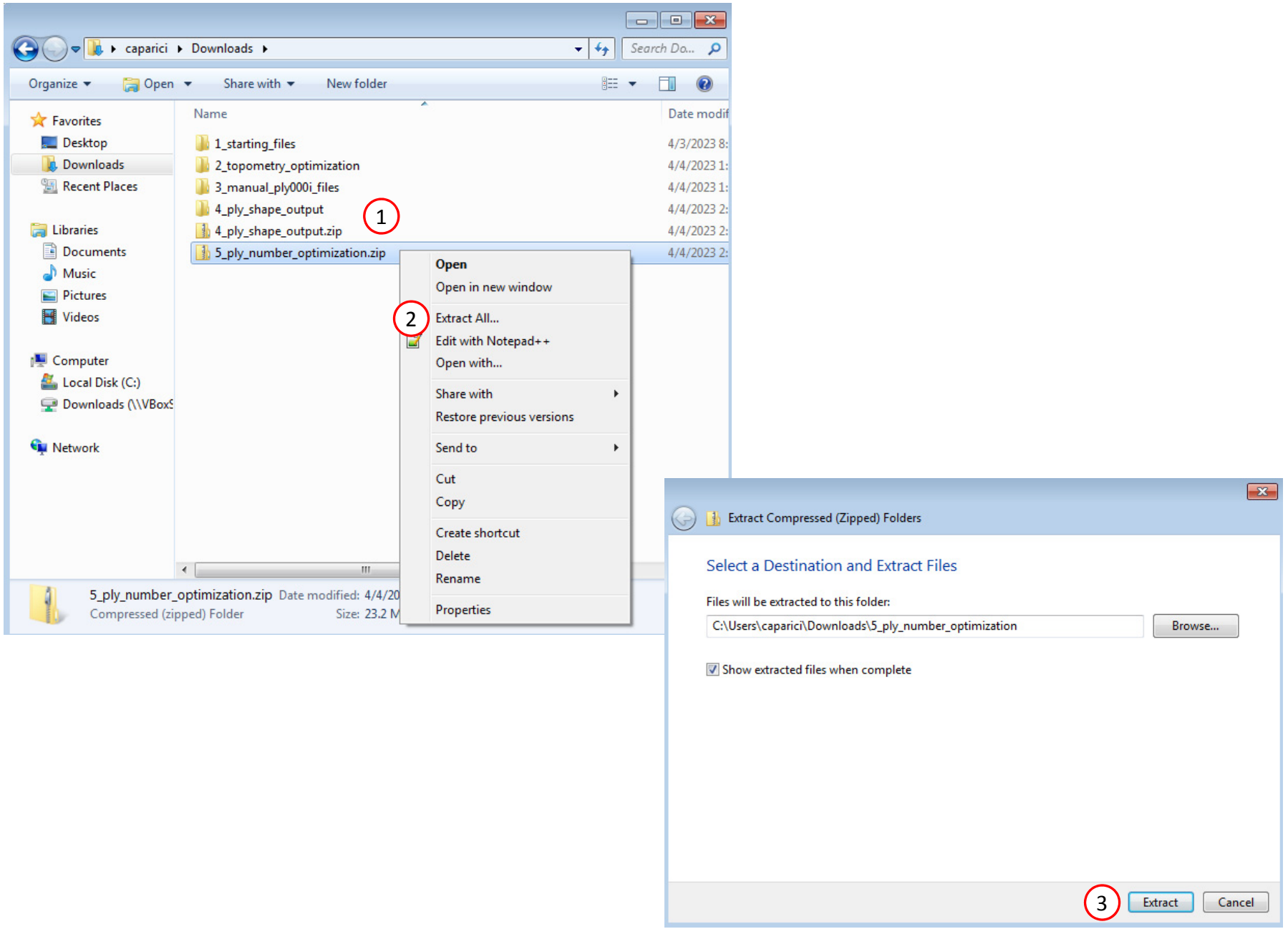
1. A new ZIP file has been downloaded
2. Rename the downloaded ZIP file to 5_ply_number_optimization.zip



Perform the Optimization with Nastran SOL 200

1. A new .zip file has been downloaded
2. Right click on the file and click Extract All
3. Click Extract on the following window

- Always extract the contents of the ZIP file to a new, empty folder.



Perform the Optimization with Nastran SOL 200

1. Inside of the new folder, double click on Start MSC Nastran
2. Click Open, Run or Allow Access on any subsequent windows
3. MSC Nastran will now start

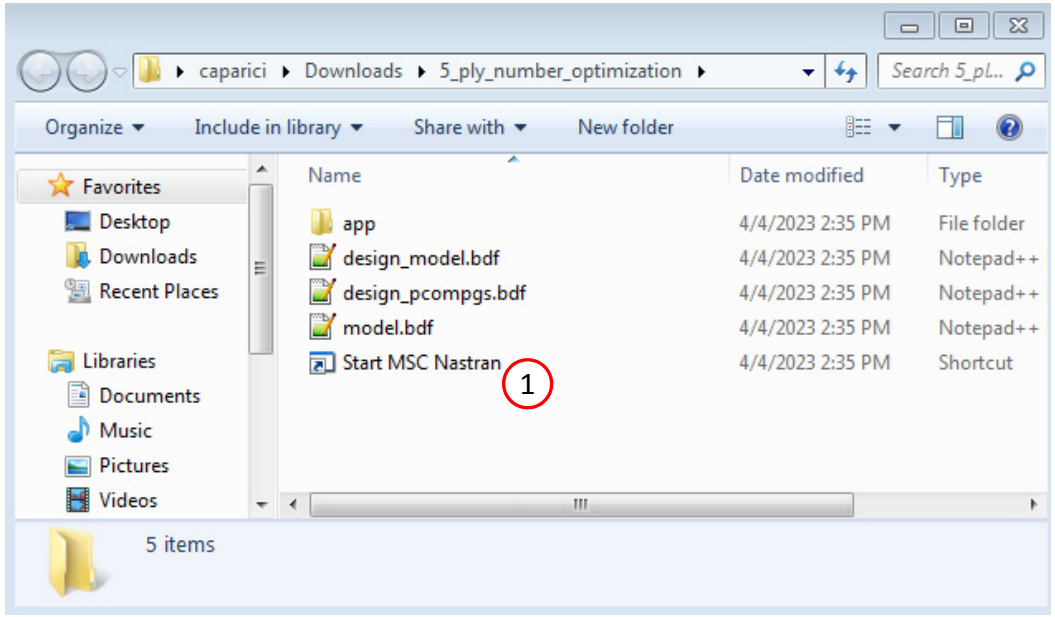
- After a successful optimization, the results will be automatically displayed as long as the following files are present: BDF, F06 and LOG.
- One can run the Nastran job on a remote machine as follows:
  1) Copy the BDF files and the INCLUDE files to a remote machine. 2) Run the MSC Nastran job on the remote machine. 3) After completion, copy the BDF, F06, LOG, H5 files to the local machine. 4) Click "Start MSC Nastran" to display the results.

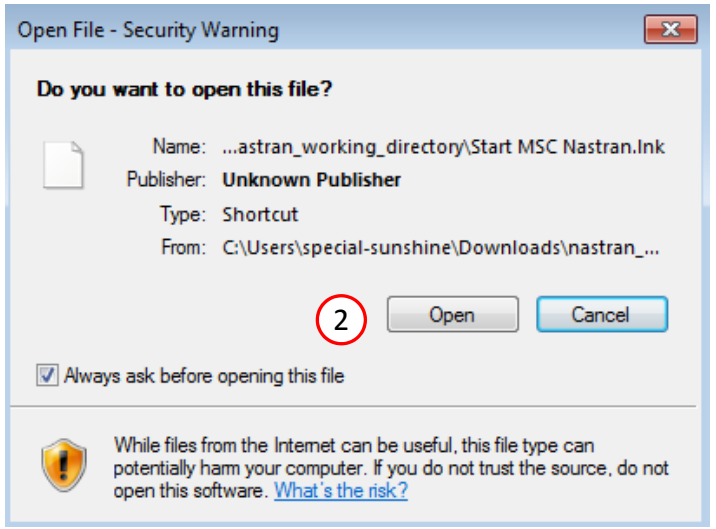
Using Linux?

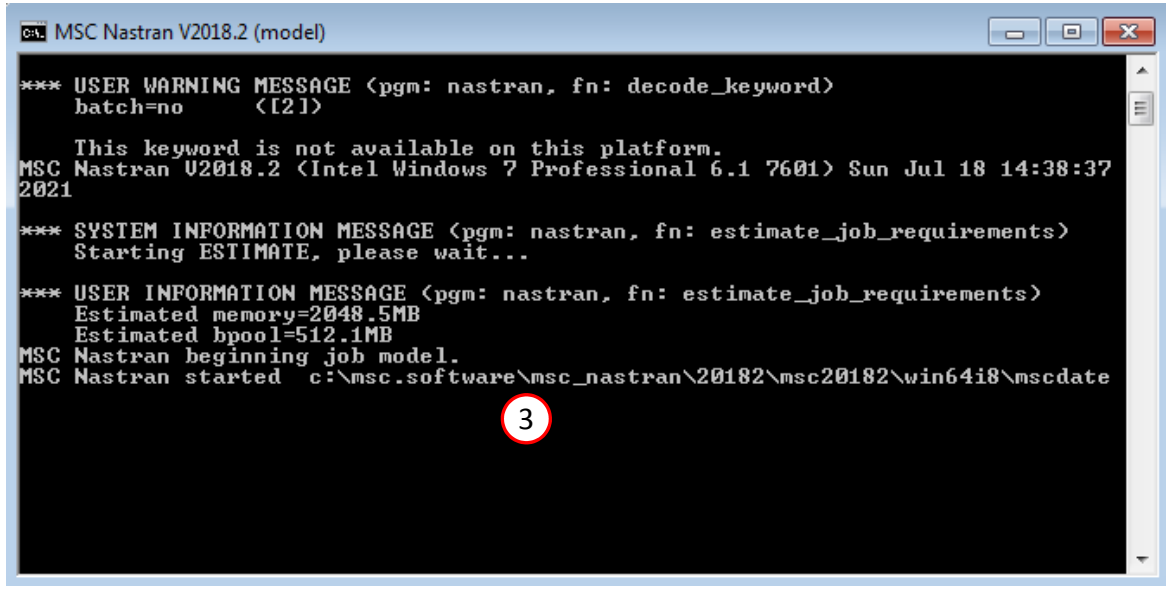
Follow these instructions:
1) Open Terminal
2) Navigate to the nastran_working_directory
cd ./nastran_working_directory
3) Use this command to start the process
./Start_MSC_Nastran.sh

In some instances, execute permission must be granted to the directory. Use this command. This command assumes you are one folder level up.

sudo chmod -R u+x ./nastran_working_directory



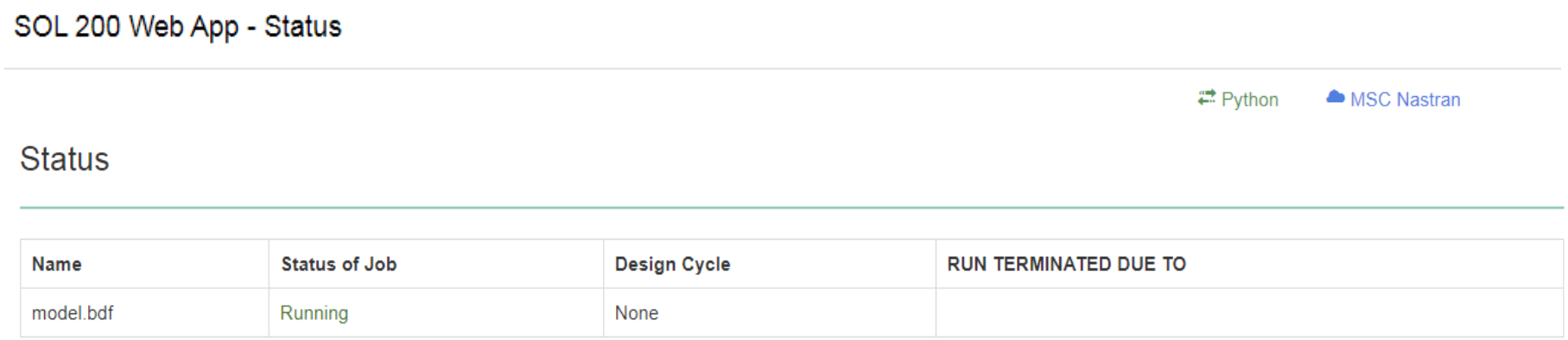




Status

1. While MSC Nastran is running, a status page will show the current state of MSC Nastran

- The status of the MSC Nastran job is reported on the Status page. Note that Windows 7 users will experience a delay in the status updates. All other users of Windows 10 and Red Hat Linux will see immediate status updates.



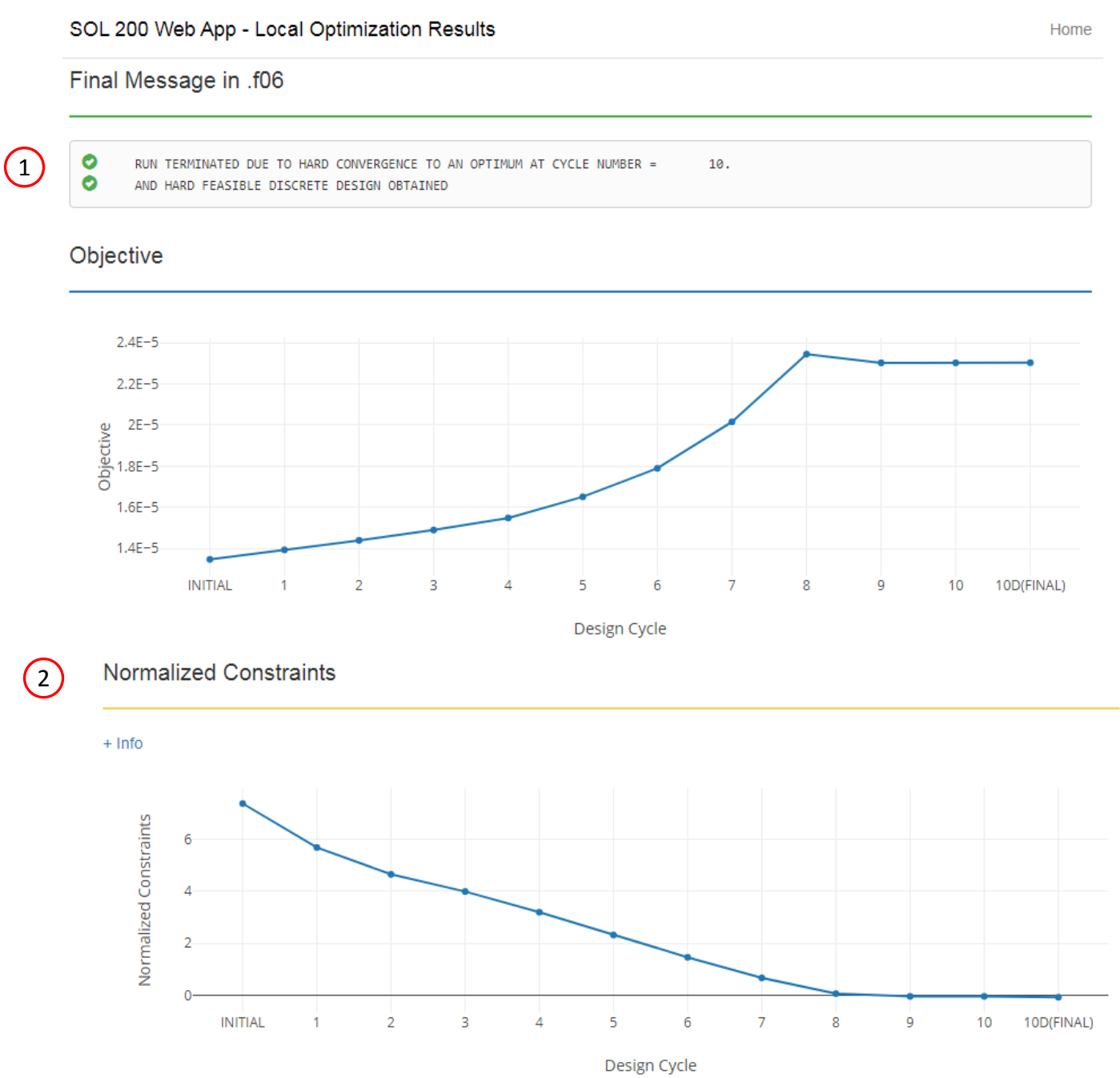
Review Optimization Results

After MSC Nastran is finished, the results will be automatically uploaded.

1. Ensure the messages shown have green checkmarks. This is indication of success. Any red icons indicate challenges.

2. The final value of objective, normalized constraints (not shown) and design variables can be reviewed.

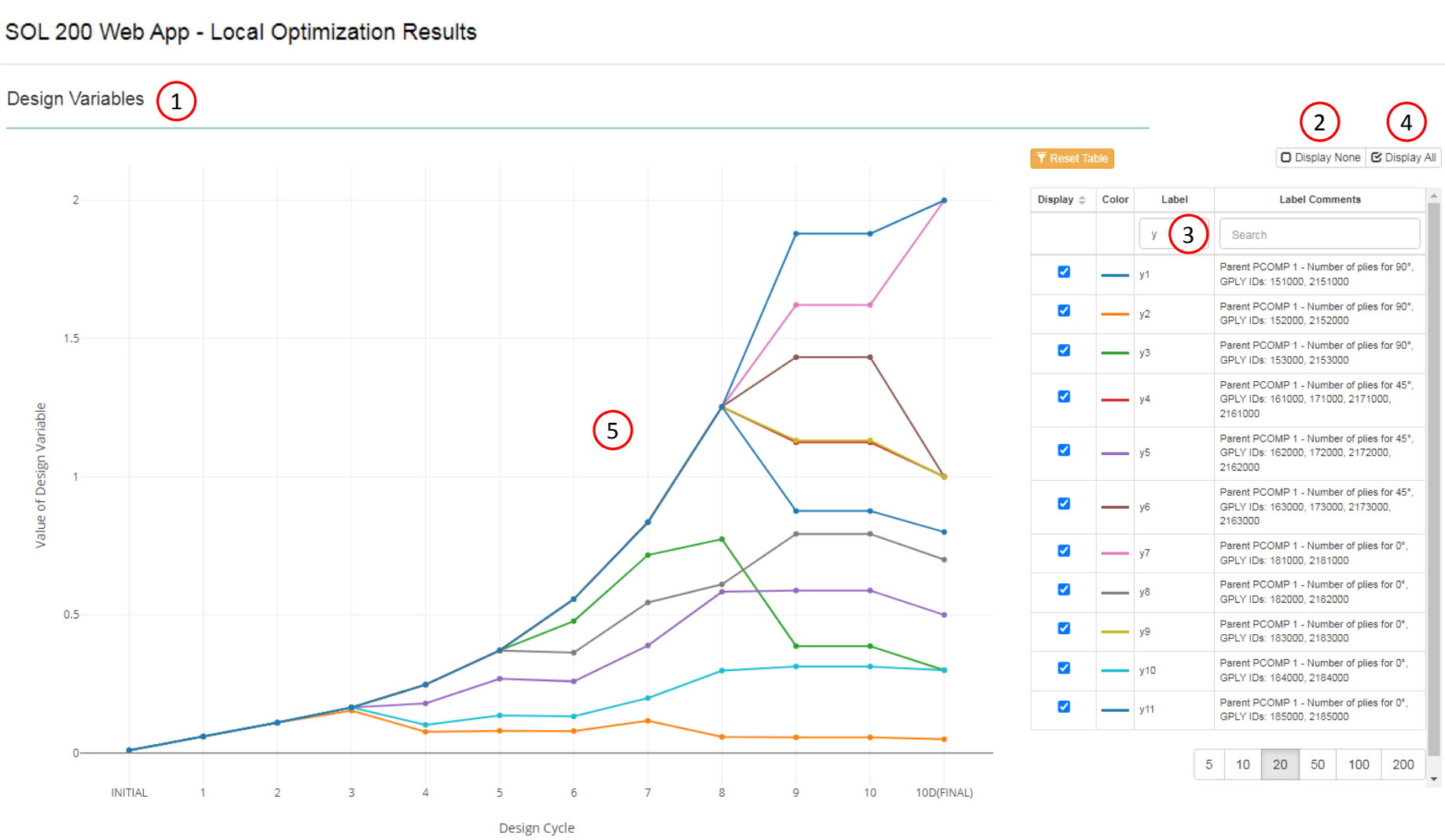
- After an optimization, the results will be automatically displayed as long as the following files are present: BDF, F06 and LOG.
- Note that the optimization solutions is sensitive to different system configurations. This optimization yielded an objective of 2.303103E-05 on Windows 7, but on Linux, yielded an objective of 2.305057E-05. Alternatively, the difference in the converged solution may be due to a difference in the surface area of the ply shape candidates. A difference of one 2D element may yield a different solution.
- Normalized constraint values that are positive indicate a design that violates at least one design constraint, and such designs are named infeasible designs. Negative normalized constraint values are desired and indicated the design satisfies all design constraints. Such designs are named feasible designs. The normalized constraint of the final design is negative, indicating a feasible design.



Review Optimization Results

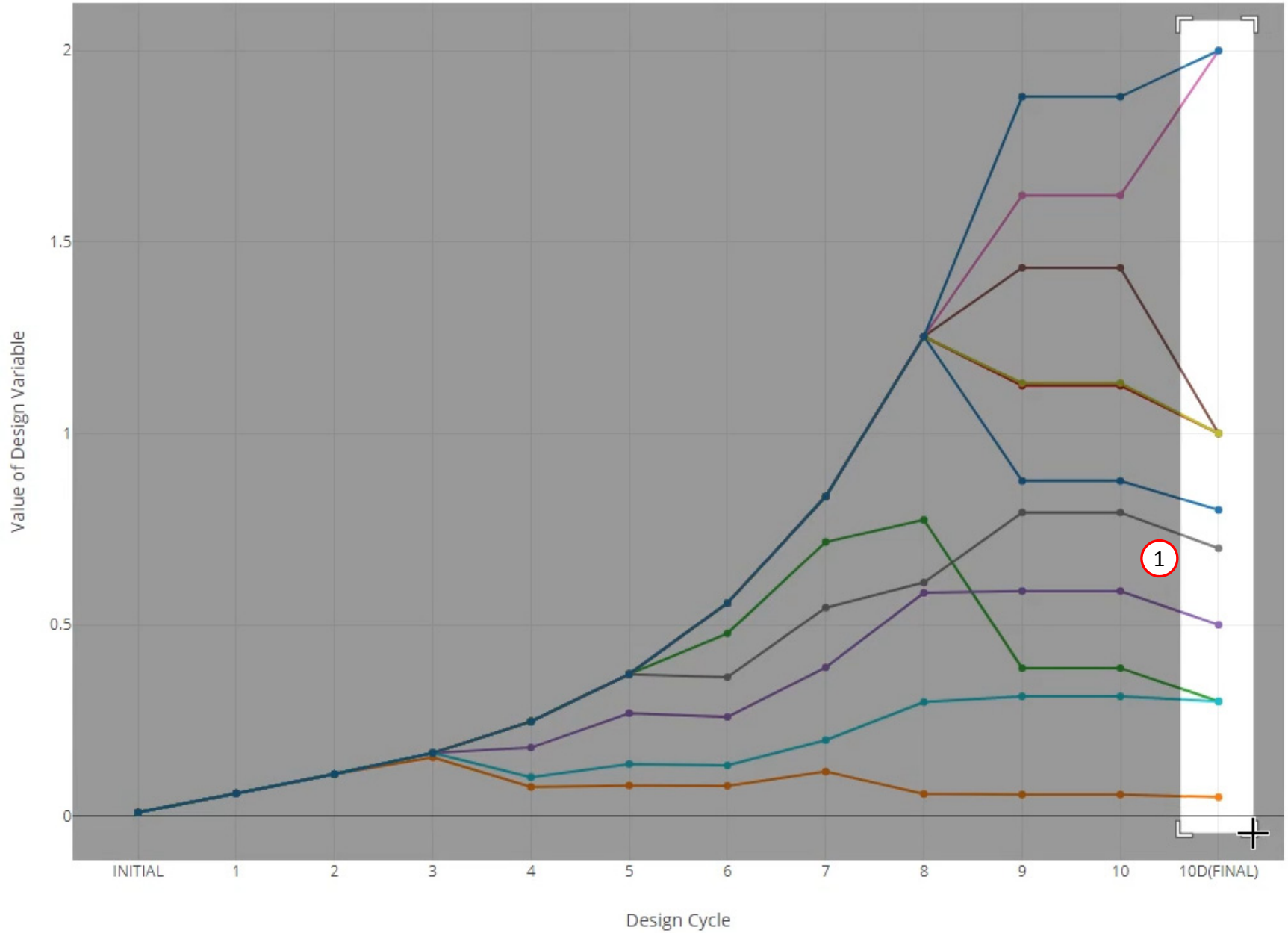
1. Navigate to section Design Variables
2. Click Display None
3. In the search box, type y
4. Click Display All
5. Only the ply number variables, e.g. y1, y2, …, are displayed

- All the thickness variables are linked to the ply number variables. On this page, the ply thickness variables are hidden and only the ply number variables are displayed.



Review Optimization Results

1. Use the mouse to click, hold and drag to create a rectangular zoom box. This will zoom into the selected region.

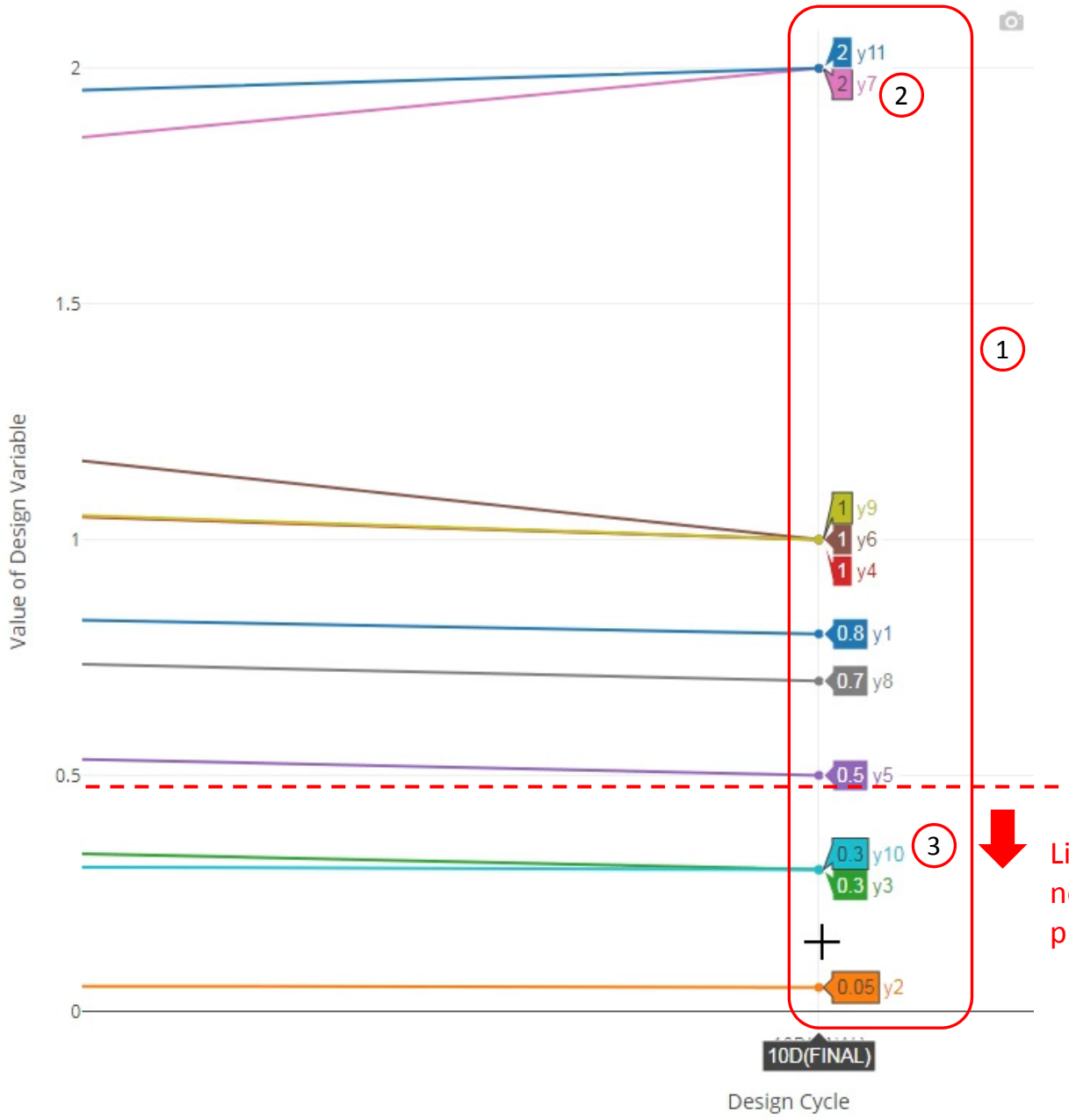


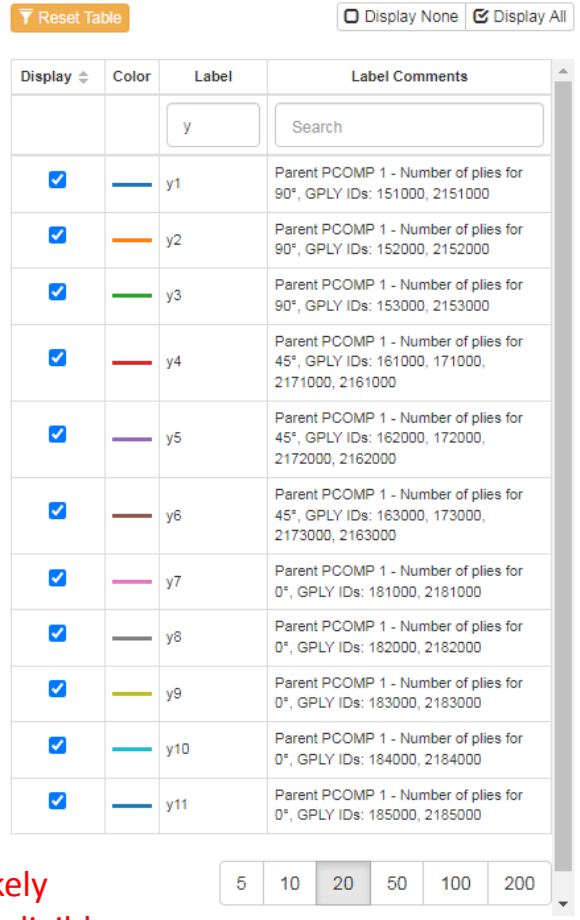
Review Optimization Results

1. Hover the mouse cursor over the points of the final design cycle and the labels will become visible.
2. Variable y7, which corresponds to GPLY ID 181000 and 2181000, has a final value of 2.
3. Variable y10, which corresponds to GPLY ID 184000 and 2184000, has a final value of 0.3.

The final values are integers and correspond to the number of plies for each ply shape that was created. If the final value is a small fractional values less than 0.5, the ply shape is deemed negligible and is automatically removed from the final BDF files in workspace_c.

- For design cycle 10, the ply number variables took on fraction values. For example, ply number variable y5 had a value of approximately .58831 in design cycle 10. When discrete values are desired for a variable, a discrete design cycle is performed, which adjusts the fractional value to an approximate discrete value. For ply number variable y5, the value of .58831 is adjusted to 0.5 in design cycle 10D, where the letter D stands for discrete.
- The optimization yielded a mass of 2.303103E-05, but this was with number variables less than 1.0. After the negligible plies are removed, e.g. y10 (184000 2184000), and the other values are rounded up to 1.0, e.g. 0.8 and 0.7 are rounded to 1.0, the final mass is actually 2.356787E-05.

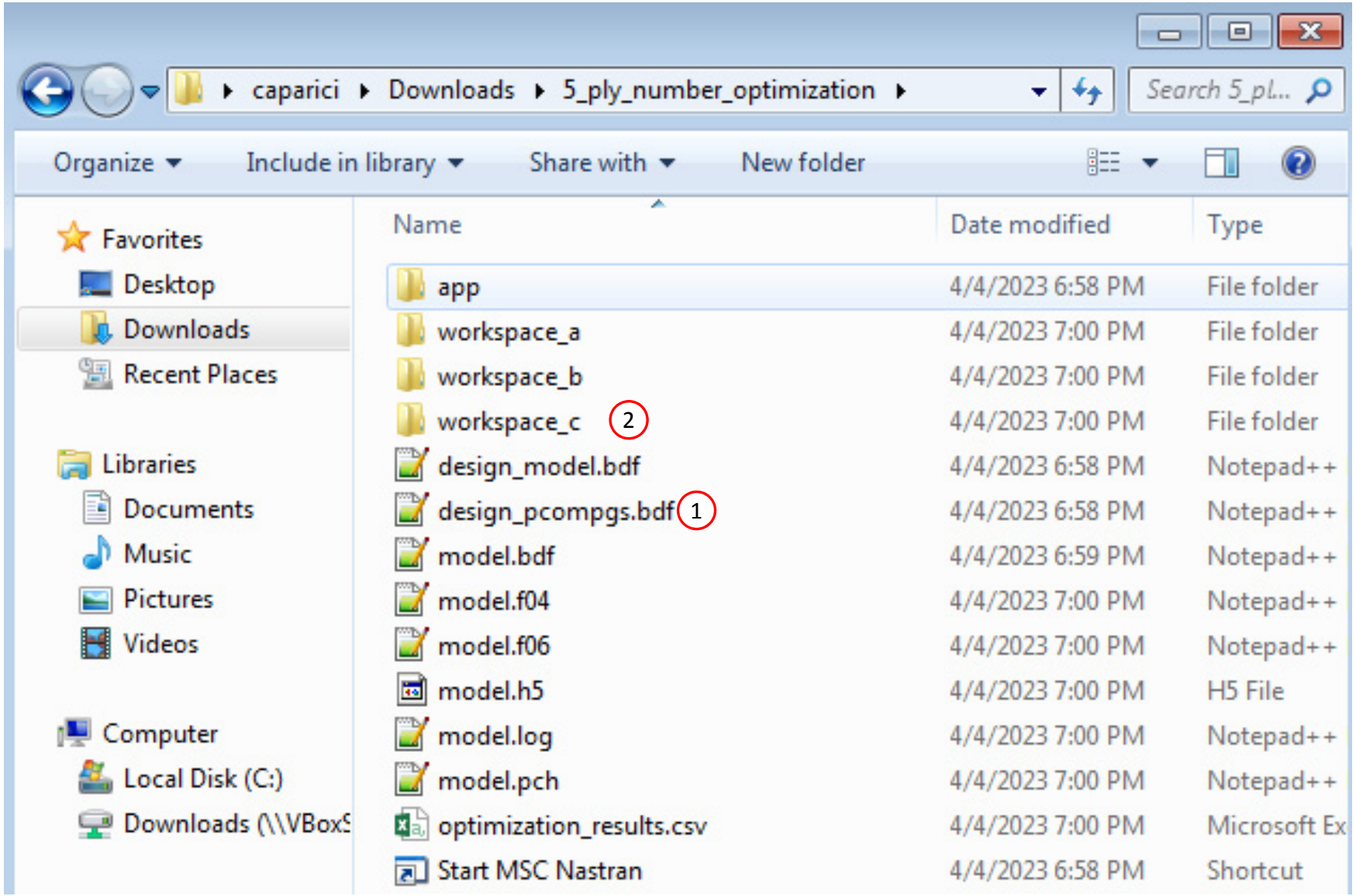




Likely negligible plies

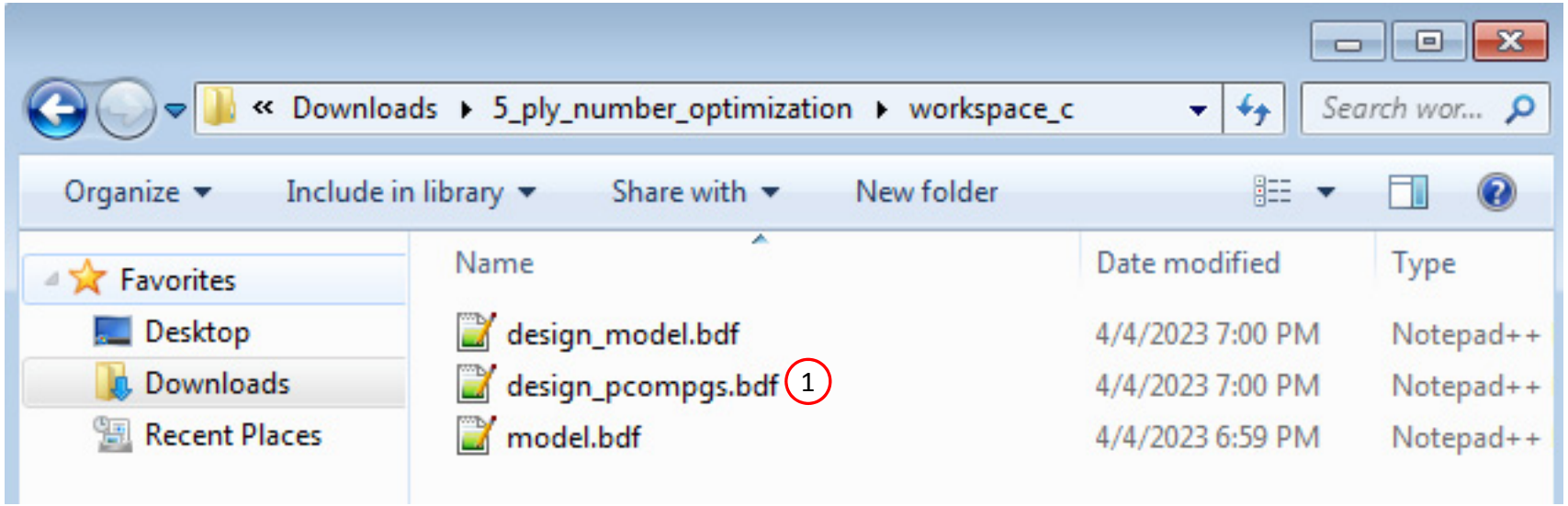
Review Optimization Results

1. Open file design_pcompgs.bdf in a text editor. A comparison will be made.
2. A new directory workspace_c has been created. Open this directory.



Review Optimization Results

1. Inside of workspace_c, open file design_pcompgs.bdf in a text editor.



Review Optimization Results

Recall the following variable results.

- Variable y7, which corresponds to GPLY ID 181000 and 2181000, has a final value of 2.
- Variable y10, which corresponds to GPLY ID 184000 and 21840000, has a final value of 0.3. Such a small ply number variable suggests the ply shape is negligible.

The following changes have been made in the BDF files found in workspace_c

1. Refer to PCOMPG 3 in both files
2. Ply shape 181000 is repeated 2 times as GPLY ID 181001 and 181002.
3. Since the composite is symmetric, the same ply shapes are mirrored as 2181001 and 2181002.
4. Ply shape 184000 and 21840000 were found to be negligible and have been removed from the final BDF files workspace_c\design_pcompgs.bdf.

The BDF files in workspace_c will be used in a future stacking sequence optimization.

.\5_ply_number_optimization\design_pcompgs.bdf

design_pcompgs.bdf

```
PCOMPG   3                              90.     HILL
         111000  101     .125    90.     YES
         121000  101     .125    45.     YES
         131000  101     .125    -45.    YES
         141000  101     .125    0.      YES
         151000  101     1.00000 90.     YES
         152000  101     1.00000 90.     YES
         161000  101     1.00000 45.     YES
         162000  101     1.00000 45.     YES
         171000  101     1.00000 -45.    YES
         172000  101     1.00000 -45.    YES
         181000  101     1.00000 0.      YES
         182000  101     1.00000 0.      YES
         184000  101     1.00000 0.      YES
         191000  501     3.175   0.      YES
         2191000 501     3.175   0.      YES
         2184000 101     1.00000 0.      YES
         2182000 101     1.00000 0.      YES
         2181000 101     1.00000 0.      YES
         2172000 101     1.00000 -45.    YES
         2171000 101     1.00000 -45.    YES
         2162000 101     1.00000 45.     YES
         2161000 101     1.00000 45.     YES
         2152000 101     1.00000 90.     YES
         2151000 101     1.00000 90.     YES
         2141000 101     .125    0.      YES
         2131000 101     .125    -45.    YES
         2121000 101     .125    45.     YES
         2111000 101     .125    90.     YES
```

.\5_ply_number_optimization\workspace_c\design_pcompgs.bdf

design_pcompgs.bdf

```
PCOMPG   3                              0.0     90.     HILL
         111000  101     .125    90.     YES
         121000  101     .125    45.     YES
         131000  101     .125    -45.    YES
         141000  101     .125    0.0     YES
         151001  101     .125    90.     YES
         161001  101     .125    45.     YES
         162001  101     .125    45.     YES
         171001  101     .125    -45.    YES
         172001  101     .125    -45.    YES
         181001  101     .125    0.0     YES
         181002  101     .125    0.0     YES
         182001  101     .125    0.0     YES
         191000  501     3.175   0.0     YES
         2191000 501     3.175   0.0     YES
         2182001 101     .125    0.0     YES
         2181002 101     .125    0.0     YES
         2181001 101     .125    0.0     YES
         2172001 101     .125    -45.    YES
         2171001 101     .125    -45.    YES
         2162001 101     .125    45.     YES
         2161001 101     .125    45.     YES
         2151001 101     .125    90.     YES
         2141000 101     .125    0.0     YES
         2131000 101     .125    -45.    YES
         2121000 101     .125    45.     YES
         2111000 101     .125    90.     YES
PCOMPG   4                              0.0     90.     HILL
         111000  101     .125    90.     YES
```

Part 3 – View New Plies

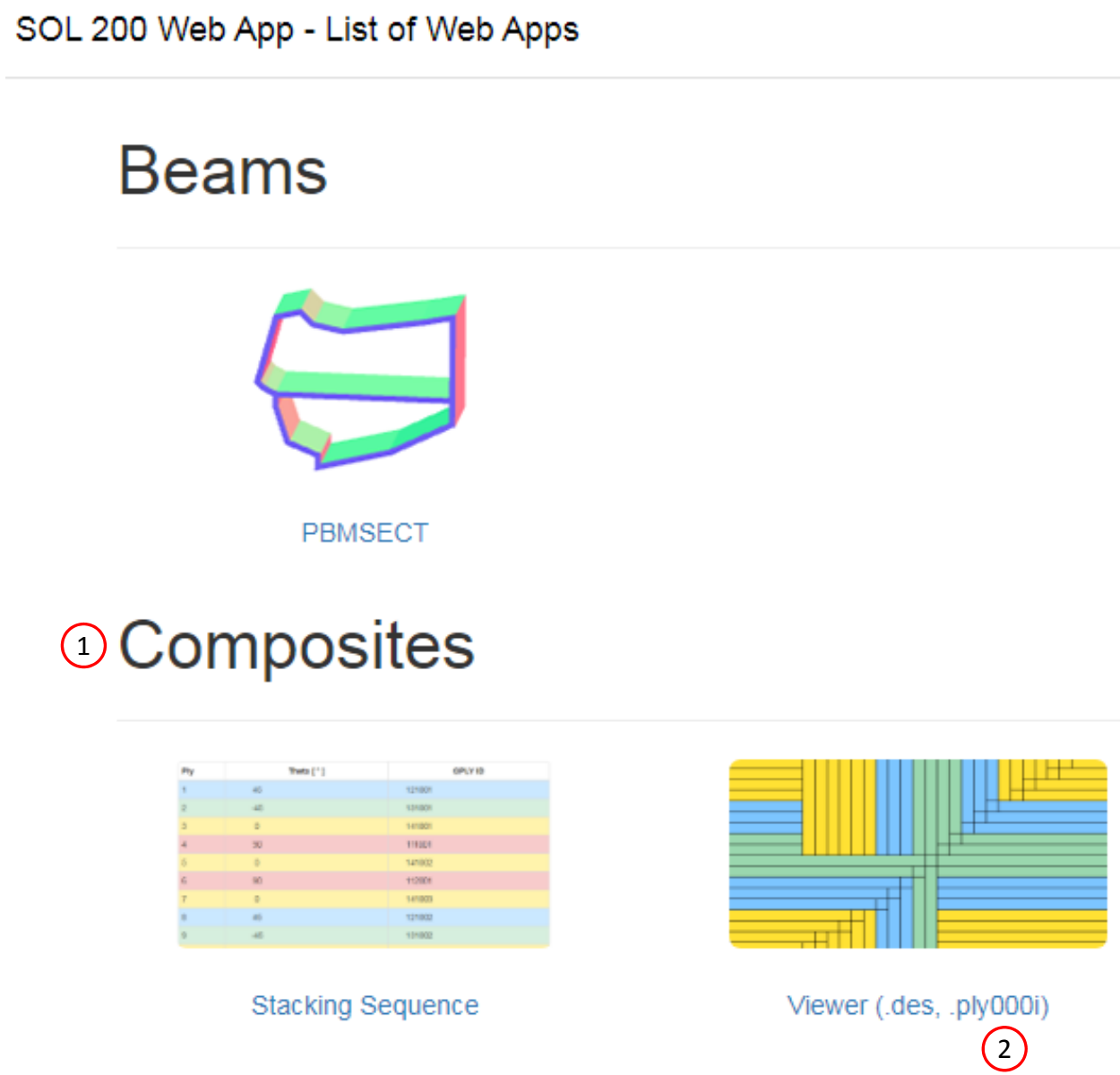
Open the Correct Page

1. Click on the indicated link

- MSC Nastran can perform many optimization types. The SOL 200 Web App includes dedicated web apps for the following:
  - Optimization for SOL 200 (Size, Topology, Topometry, Topography, Local Optimization, Sensitivity Analysis and Global Optimization)
  - Multi Model Optimization
  - Machine Learning
- The web app also features the HDF5 Explorer, a web application to extract results from the H5 file type.

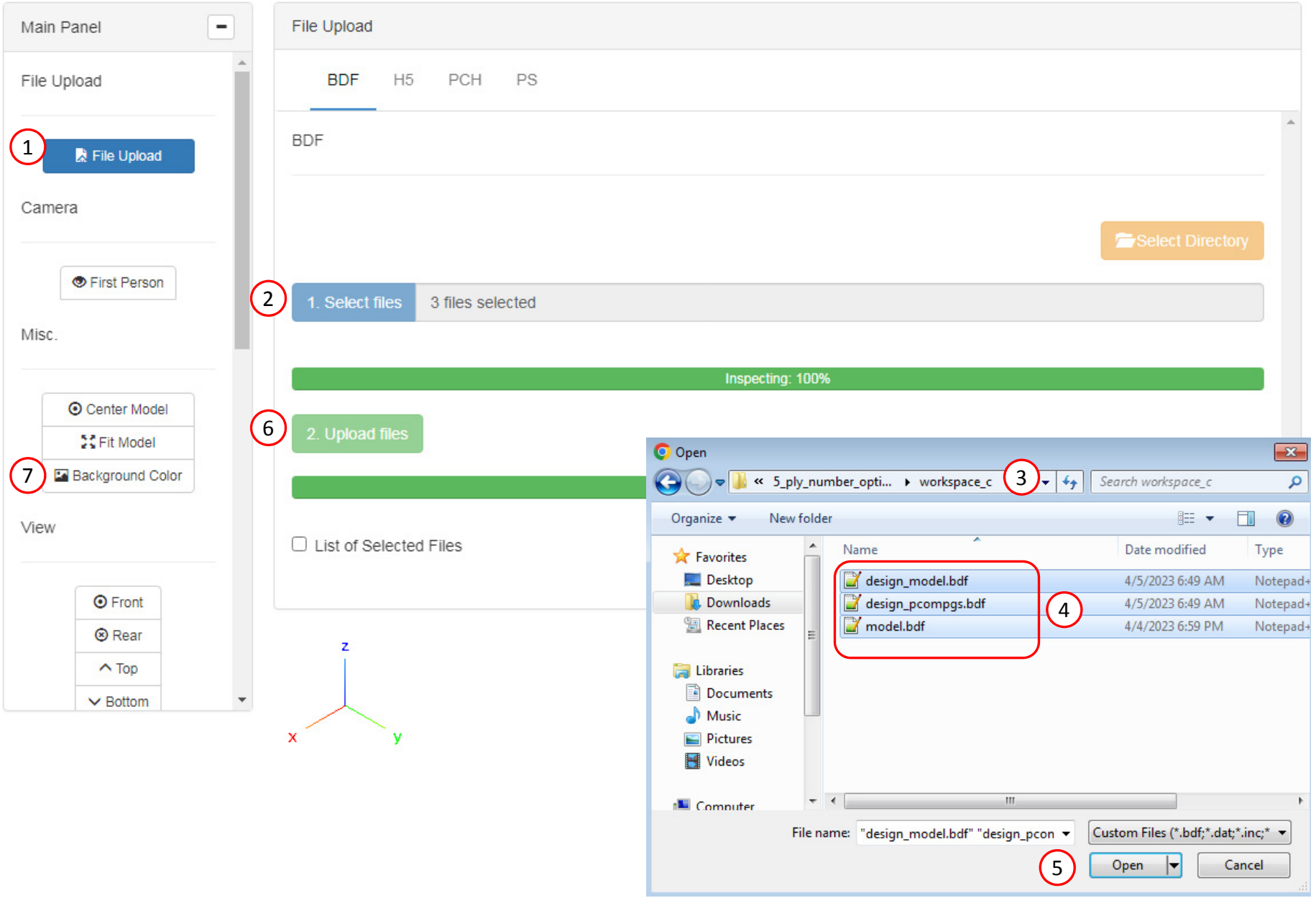
Open the Viewer

1. Navigate to the Composites section
2. Click Viewer



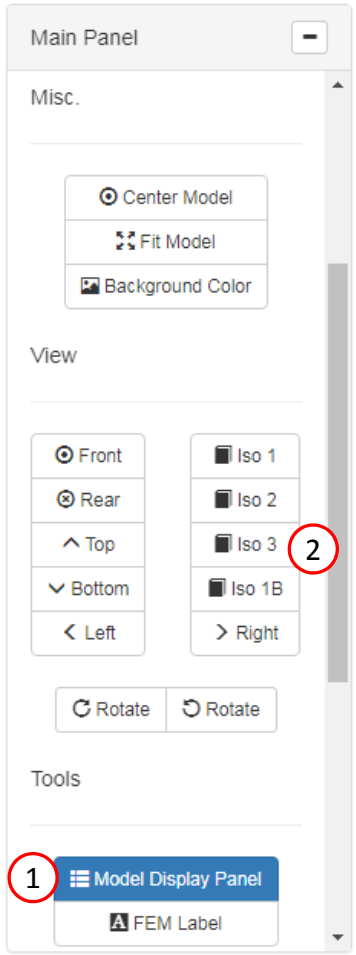
Upload BDF Files

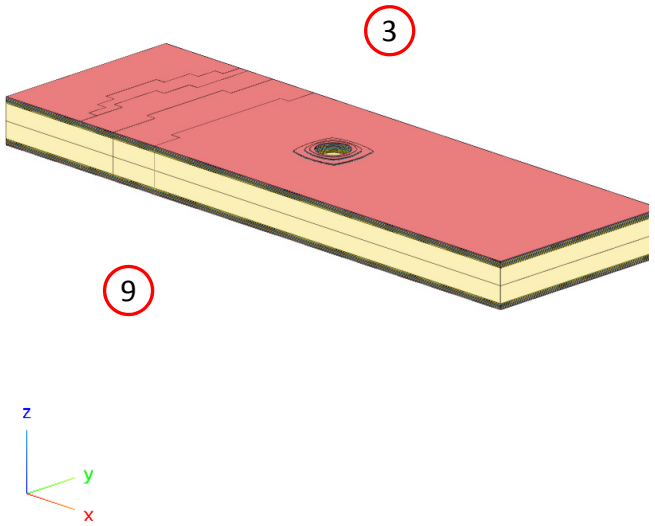
1. Click File Upload
2. Click Select files
3. Navigate to directory workspace_c
4. Select the indicated files
5. Click Open
6. Click Upload files
7. Click Background Color (Optional)

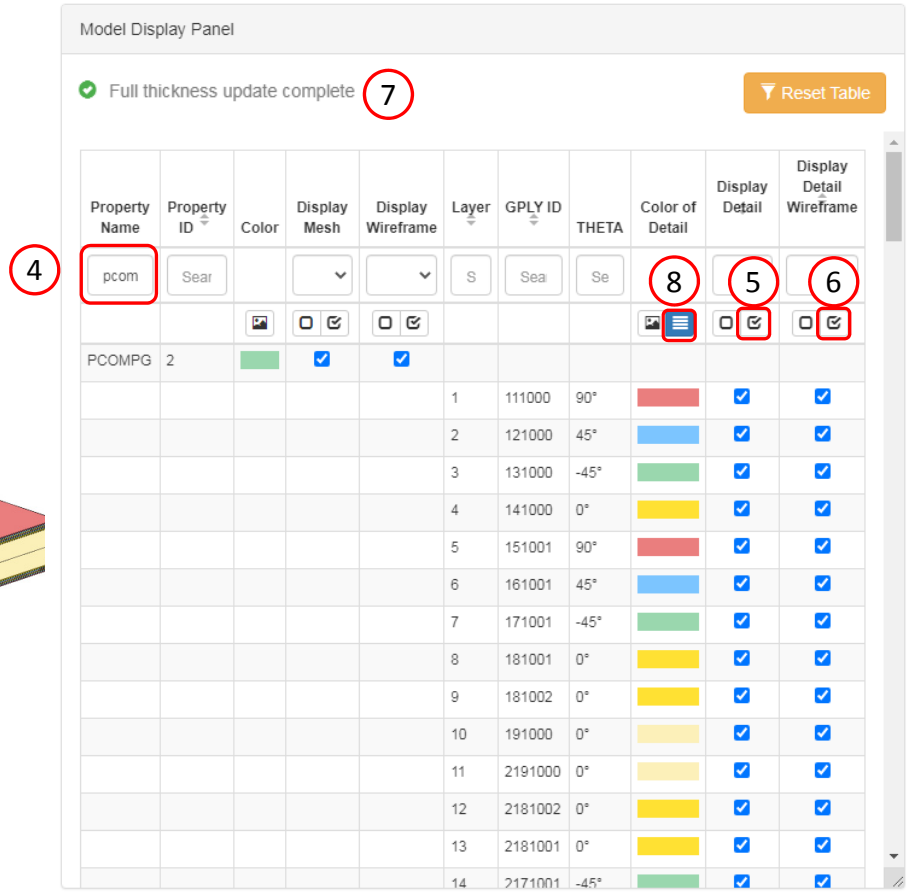


Display PCOMPGs

1. Click Model Display Panel
2. Click Iso 3
3. Right click and hold the right mouse button, and move the mouse to translate the model into view.
4. In the search box, type: pcompg
5. Click the indicated icon
6. Click the indicated icon
7. If an update message appears, wait until the update is complete, then continue
8. Click the indicated icon to recolor the plies
9. The layer thicknesses is now displayed

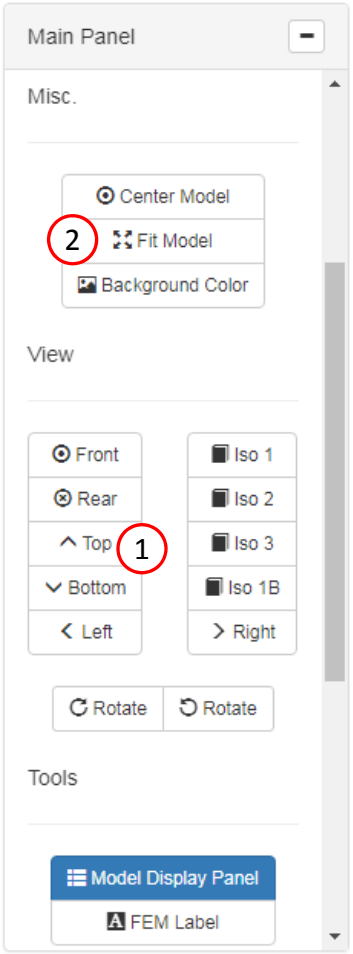


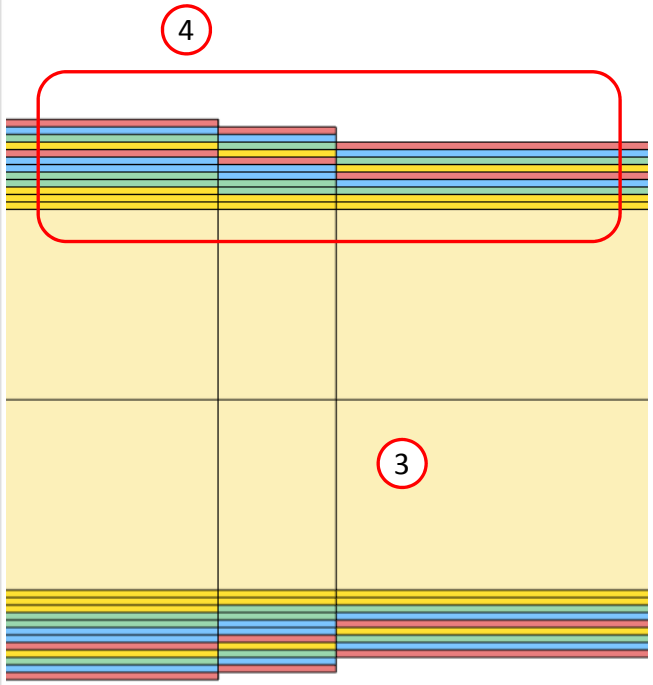


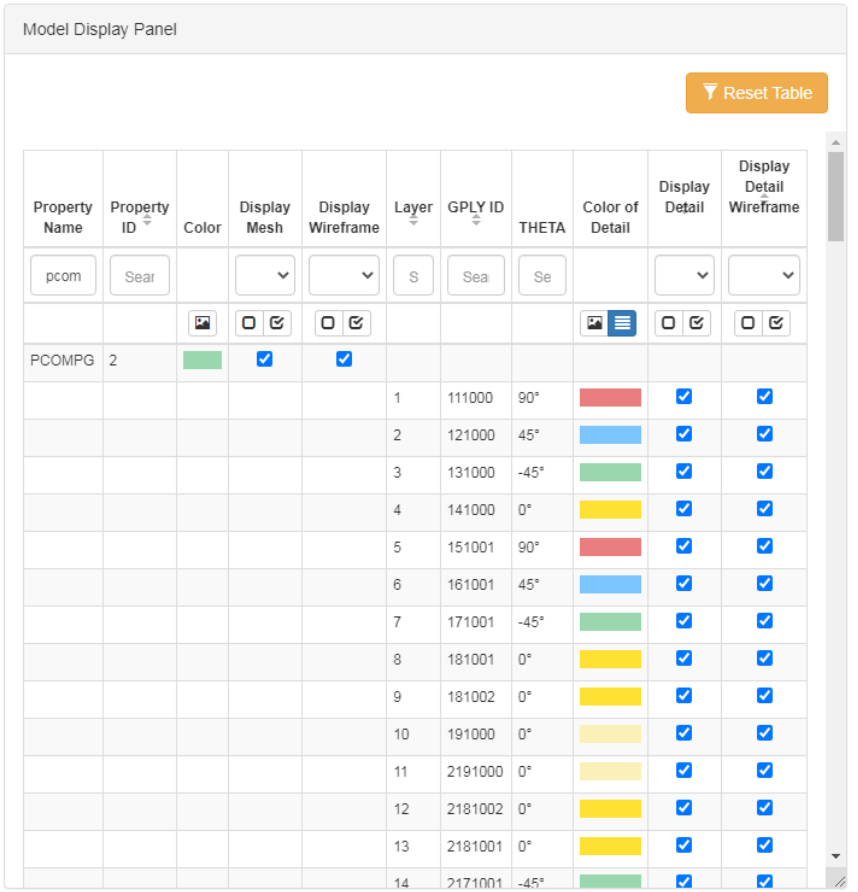


Display PCOMPGs

1. Click Top
2. Click Fit Model
3. Use the mouse scroll wheel to zoom in
4. The ply thickness varies throughout the composite. The current view is a literal view of the PCOMPG entries.



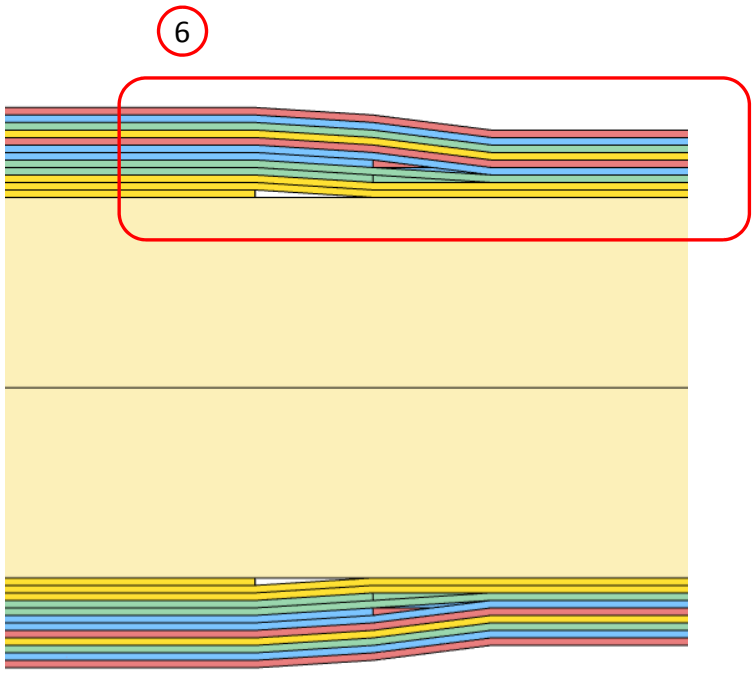




Display GPLYs

1. Click the indicated icons
2. Click Reset Table
3. In the search box, type: gply
4. Click the indicated icons
5. Click the indicated icon 2 times
6. A more realistic view of the plies is displayed

- Alternate between the literal and realistic views to gain a good understanding of how the plies are distributed across the model.



Model Display Panel

2 Reset Table

Property Name	Property ID	Color	Display Mesh	Display Wireframe	Layer	GPLY ID	THETA	Color of Detail	Display Detail	Display Detail Wireframe
gply	Sear				S	Sea	Se			
GPLY	111000					111000	90°			
GPLY	121000					121000	45°			
GPLY	131000					131000	-45°			
GPLY	141000					141000	0°			
GPLY	151001					151001	90°			
GPLY	161001					161001	45°			
GPLY	162001					162001	45°			
GPLY	163001					163001	45°			
GPLY	171001					171001	-45°			
GPLY	172001					172001	-45°			
GPLY	173001					173001	-45°			
GPLY	181001					181001	0°			
GPLY	181002					181002	0°			
GPLY	182001					182001	0°			
GPLY	183001					183001	0°			
GPLY	185001					185001	0°			

3 5 4 1

Summary of Optimized Designs

A comparison is made between the starting and final composite designs from phase D. Observe the following:

1. ~21% mass savings. The mass of the plies was reduced from 2.229851E-05 to 1.76E-05.
2. For the final composite, after stacking sequence optimization, the maximum failure index is .838 and is well under the upper allowed limit of .95.

The ply shape and ply number optimization has been a success.

	Starting Design	Design After Ply Shape and Ply Number Optimization	Design After Stacking Sequence Optimization
	Tutorial Phase B	Tutorial Phase D	Tutorial Phase E
Total Mass	2.825148E-05	2.356787E-05	2.356787E-05
Mass of Non-design Region (Core)	5.952966E-06	5.952966E-06	5.952966E-06
Mass of Design Region (Plies)	**2.229851E-05**	**1.76E-05**	**1.76E-05**
Max Failure Index , Subcase 1	.905 (OK)	.838 (OK)	.838 (OK)
Max Failure Index, Subcase 2	.934 (OK)	.856 (OK)	.654 (OK)

End of Tutorial

Appendix

Appendix Contents

- What filter values to use?
- PCOMPG Zones
- Options for Ply Number Optimization
- GPLY ID Numbering Convention (sPLC000)
- Optimizing Composite Ply Shapes and Numbers for Uniaxial Loading
- Optimizing Composite Ply Shapes and Numbers for Bending

What filter values to use?

What filter values to use?

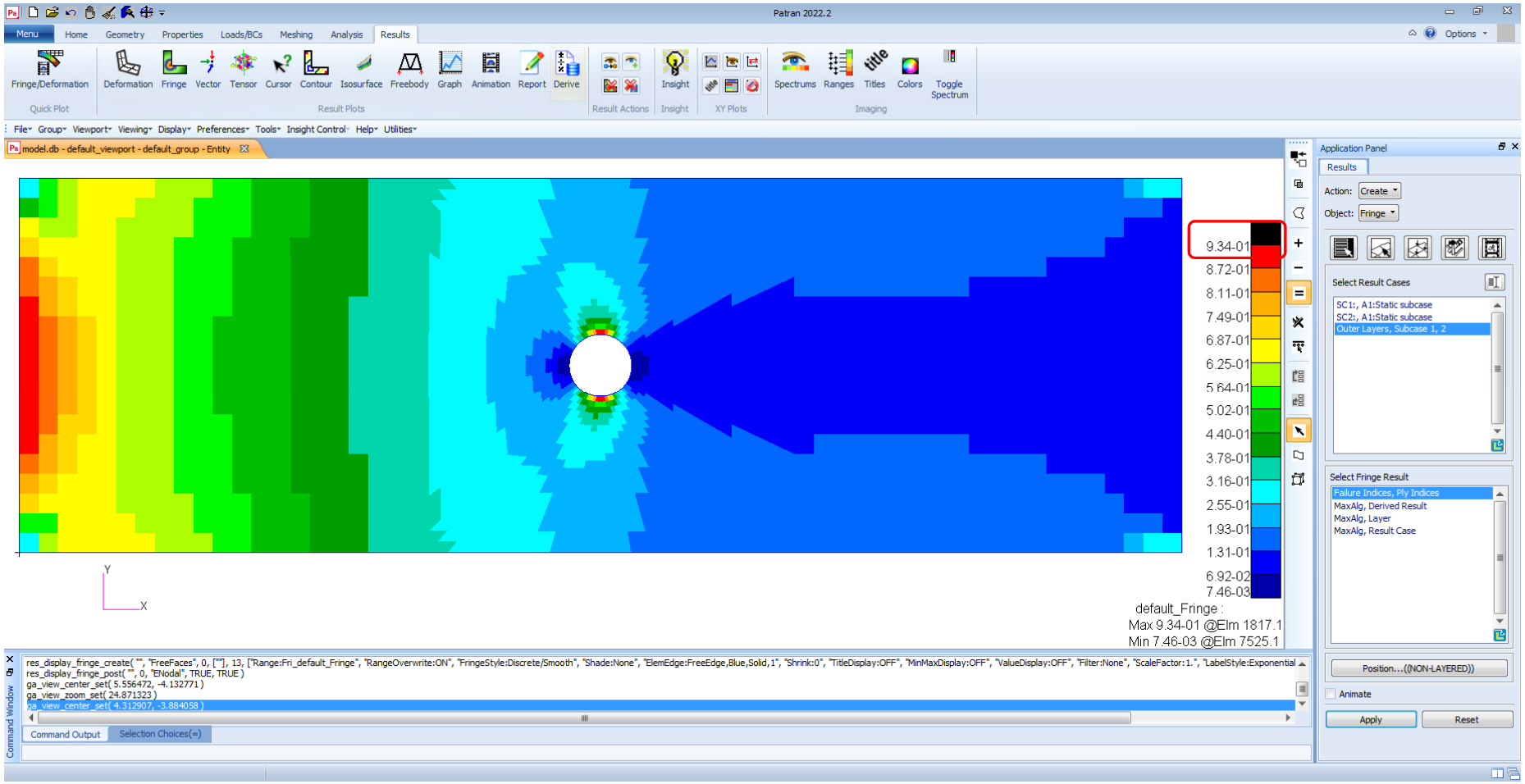
In this exercise, certain values were used for the threshold. How were these values obtained?

Display Ply Shape	Include in PCOMPGs	GPLY ID	Ply	Candidate	Dependent On Ply	Theta	Action	Threshold Slider	Threshold	Pick Mode	Number of Elements
☐	☑	111000	1	1		90°	+		0		2280
☐	☑	121000	2	1		45°	+		0		2280
☐	☑	131000	3	1	2	-45°	+		0		2280
☐	☑	141000	4	1		0°	+		0		2280
☐	☑	151000	5	1		90°	+		0		2280
☐	☑	152000	5	2		90°	×		0.47		268
☐	☑	153000	5	3		90°	×		0.47		268
☐	☑	161000	6	1		45°	+		0		2280
☐	☑	162000	6	2		45°	×		0.21		208
☐	☑	163000	6	3		45°	×		0.21		208
☐	☑	171000	7	1	6	-45°	+		0		2280
☐	☑	172000	7	2	6	-45°	×		0.21		208
☐	☑	173000	7	3	6	-45°	×		0.21		208
☐	☑	181000	8	1		0°	+		0		2280
☐	☑	182000	8	2		0°	×		0.03		157
☐	☑	183000	8	3		0°	×		0.03		157
☐	☑	184000	8	4		0°	×		0.02		414
☐	☑	185000	8	5		0°	×		0.02		414
☑	☑	191000	9	1		0°	+		0		2280

What filter values to use?

Recall that the maximum failure index of the outer 90° plies was originally determined and stored in file model.ply0005. Ply shape candidates were created based on the failure index values.

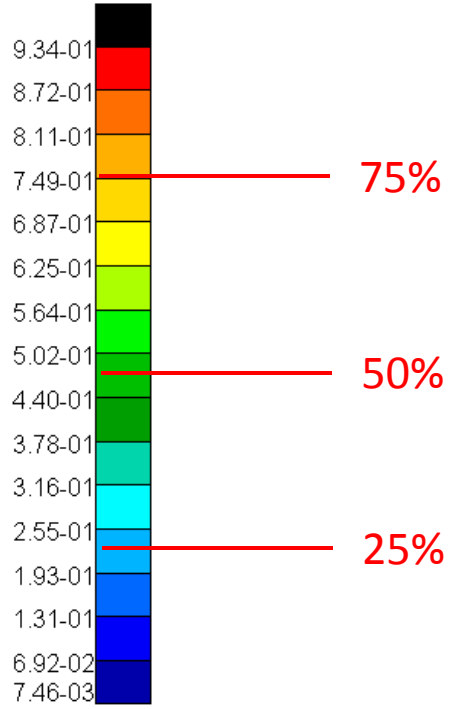
1. The maximum failure index was found to be 0.934.



What filter values to use?

- The value 0.934 was divided by 2 (50%) to yield 0.47.
- If more ply shape candidates are desired, additional ply shapes may be constructed with different threshold values, e.g. 10%, 20%, 30% or other percentages.

Display Ply Shape	Include in PCOMPGs	GPLY ID	Ply	Candidate	Dependent On Ply	Theta	Action	Threshold Slider	Threshold	Pick Mode	Number of Elements
☐	☑	111000	1	1		90°	+		0		2280
☐	☑	121000	2	1		45°	+		0		2280
☐	☑	131000	3	1	2	-45°	+		0		2280
☐	☑	141000	4	1		0°	+		0		2280
☐	☑	151000	5	1		90°	+		0		2280
☐	☑	152000	5	2		90°	×		0.47		268
☐	☑	153000	5	3		90°	×		0.47		268

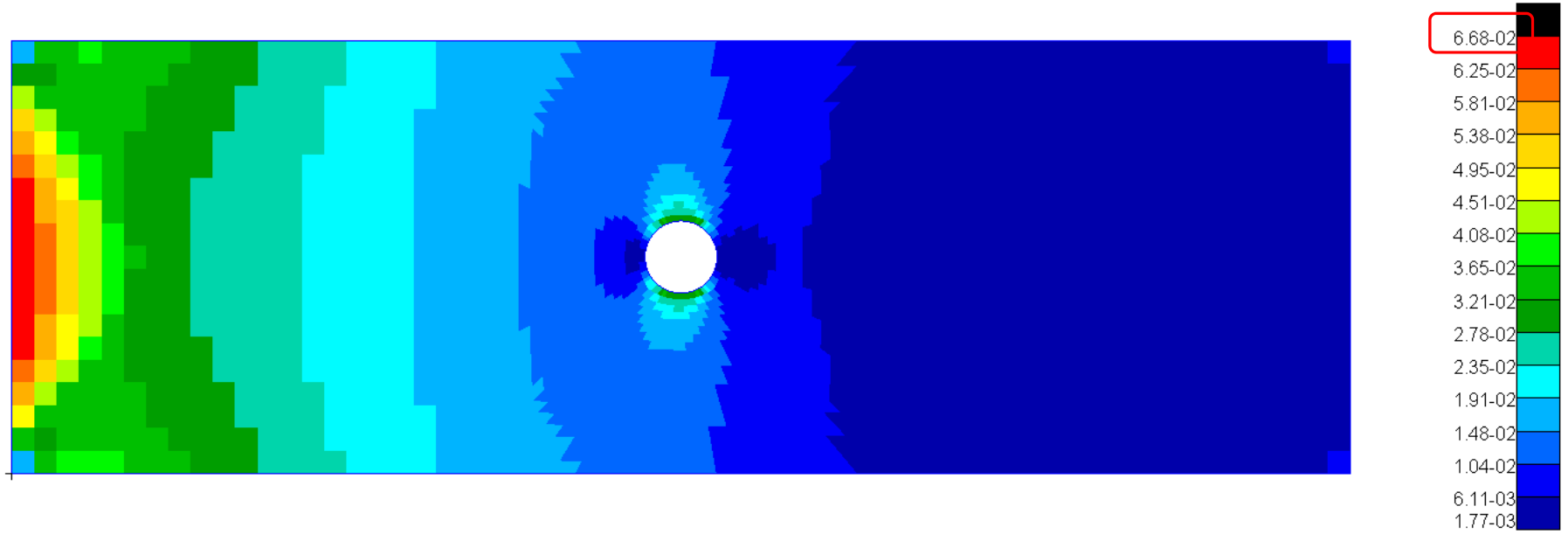


What filter values to use?

1. A similar procedure was done for the +45°, -45° and 0° plies.

2. In the case of the 0° plies, whose values are stored in file model.ply0008, the maximum value was found to be .0668. Taking 50% and 25% of the maximum value yields .03 and .02.

☐	☑	182000	8	2		0°	✖		0.03		157
☐	☑	183000	8	3		0°	✖		0.03		157
☐	☑	184000	8	4		0°	✖		0.02		414
☐	☑	185000	8	5		0°	✖		0.02		414



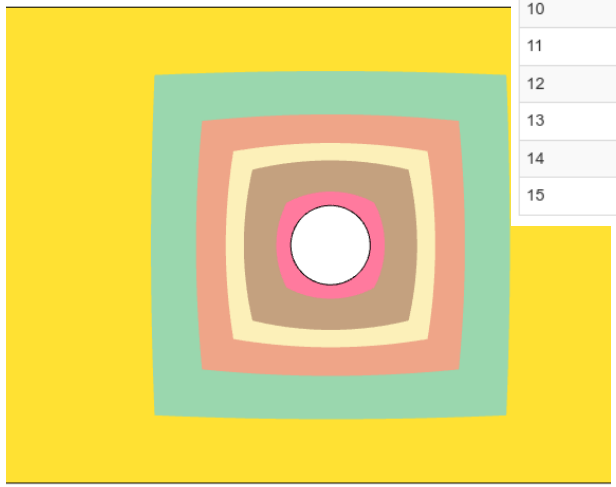
PCOMPG Zones

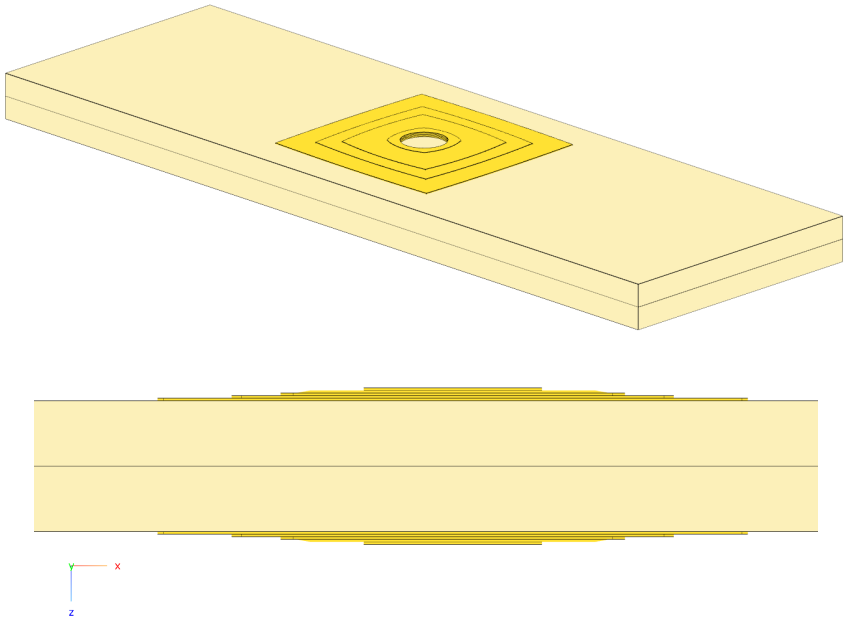
PCOMPG Zones

The ply shapes in the final composite may be controlled. When ply shapes are included or excluded, the PCOMPG zones will vary. Inspect the PCOMPG zones since these zones indicate what the final composite will look like.

More Ply Shapes

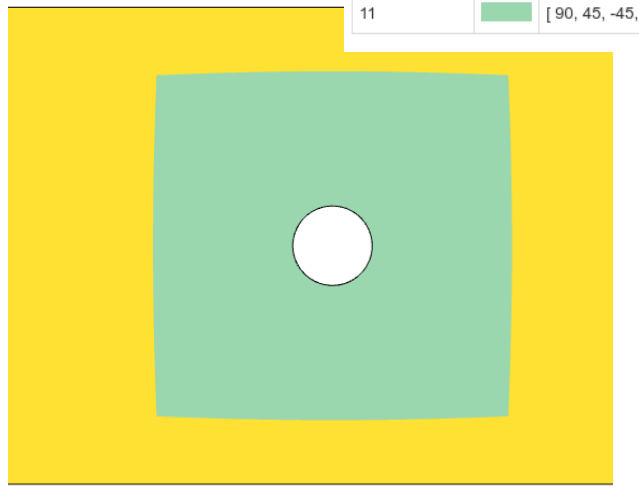
PCOMPG ID	Color	Stack
10		[90, 45, -45, 0, 0_{Core}]S
11		[90, 45, -45, 0_2, 0_{Core}]S
12		[90, 45, -45, 0_3, 0_{Core}]S
13		[90, 45, -45, 0_4, 0_{Core}]S
14		[90, 45, -45, 0_5, 0_{Core}]S
15		[90, 45, -45, 0_6, 0_{Core}]S

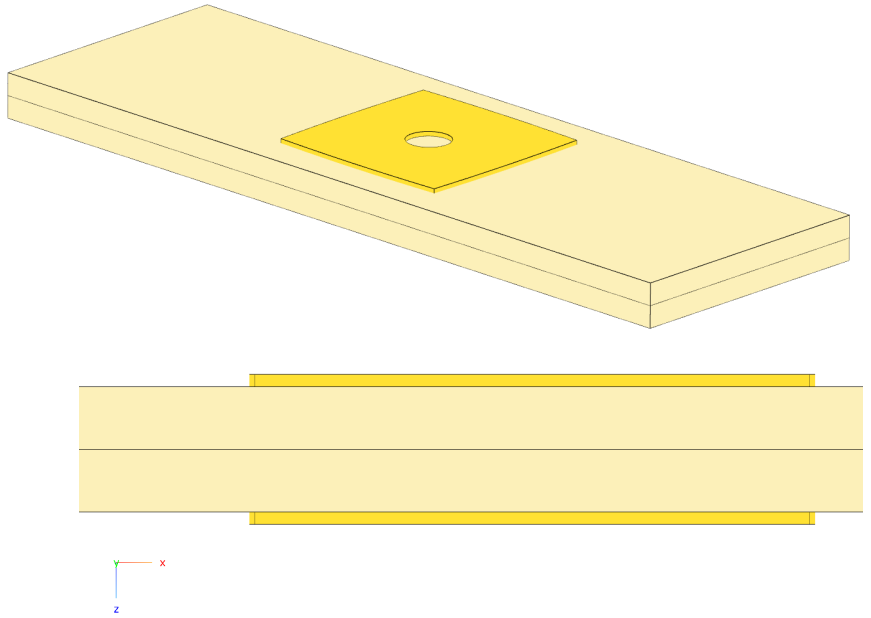




Fewer Ply Shapes

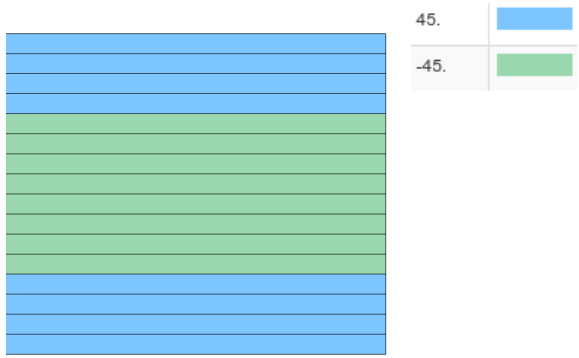
PCOMPG ID	Color	Stack
10		[90, 45, -45, 0, 0_{Core}]S
11		[90, 45, -45, 0_2, 0_{Core}]S



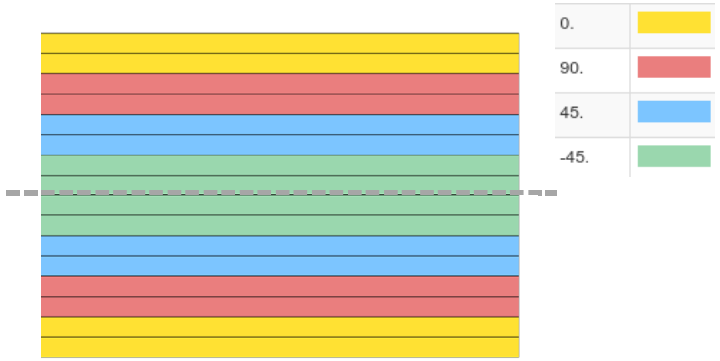


Options for Ply Number Optimization

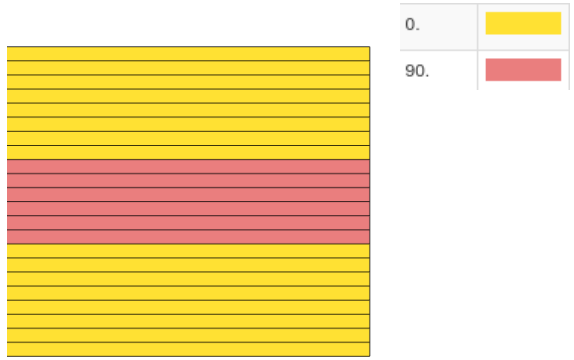
Options for Ply Number Optimization



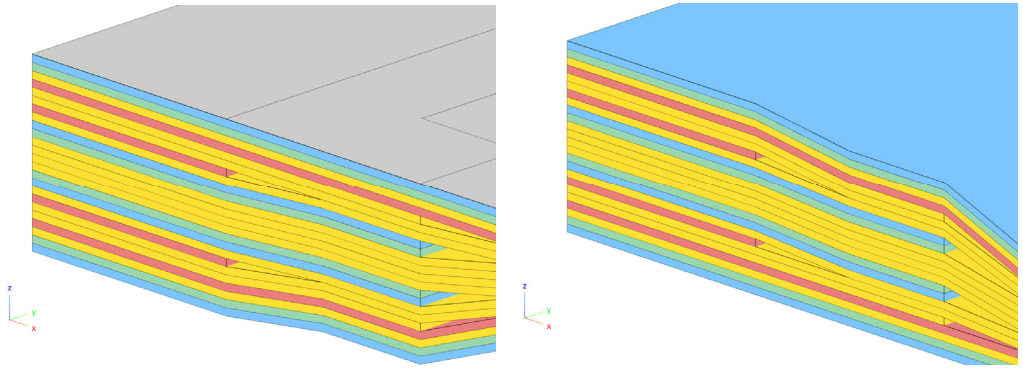
Balance



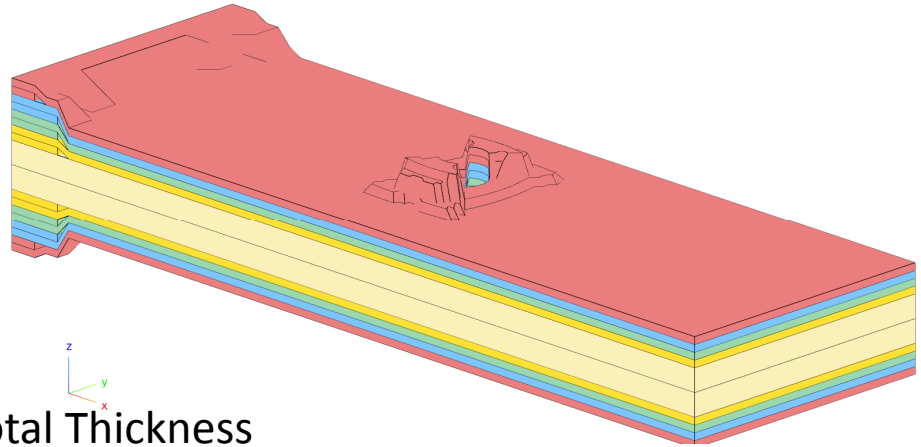
Symmetry



X% Design Rule



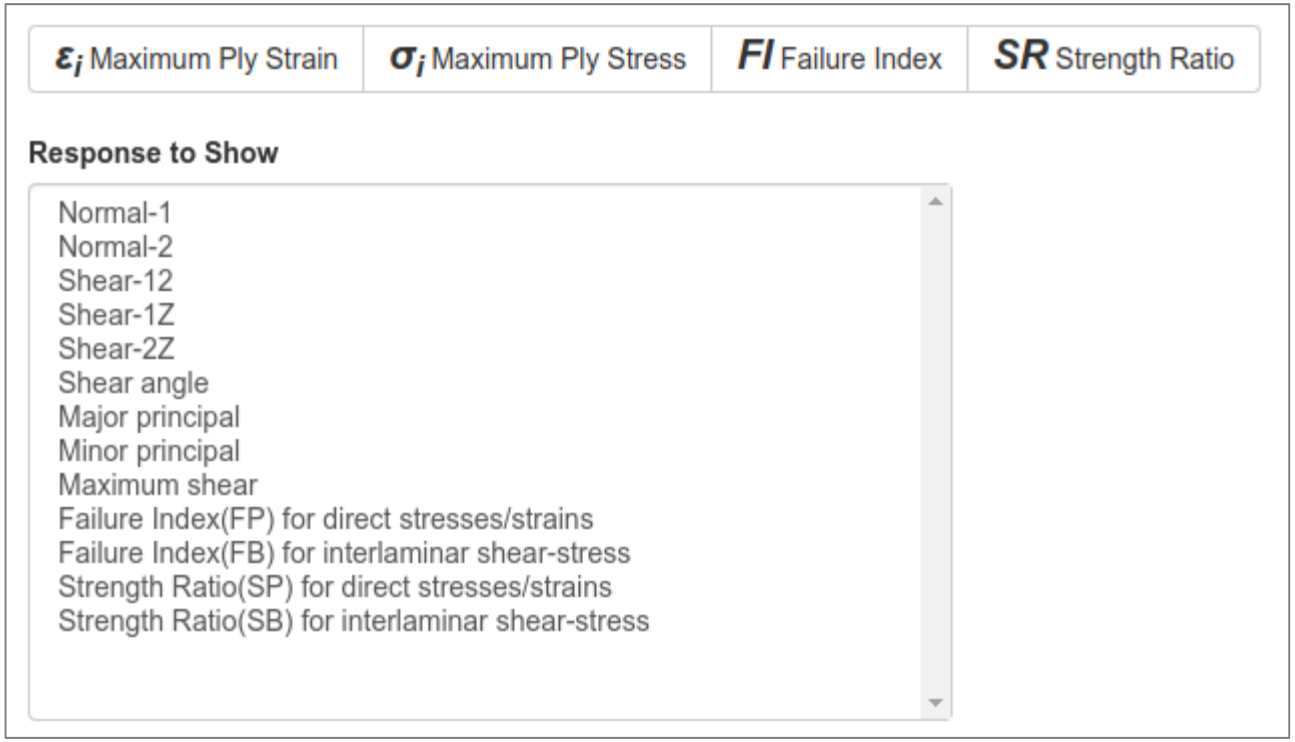
Z0 Offset



Total Thickness

Options for Ply Number Optimization
Constraints on Responses

Constraints on Responses
- Ply Stress
- Ply Strain
- Failure Index
- Strength Ratio
- And more



Options for Ply Number Optimization
Constraints on Responses

Response	Stress	Strain
Normal-1	σ_1	ε_1
Normal-2	σ_2	ε_2
Shear-12	τ_{12}	γ_{12}
Shear-1Z	τ_{xz}	γ_{xz}
Shear-2Z	τ_{yz}	γ_{yz}
Shear Angle	θ_p	θ_p
Major Principal	σ_{max}	ε_{max}
Minor Principal	σ_{min}	ε_{min}
Maximum shear	τ_{max}	γ_{max}
Failure Index(FP) for direct stresses/strains	FP	
Failure Index(FB) for interlaminar shear-stress	FB	
Strength Ratio(SP) for direct stresses/strains	SP	
Strength Ratio(SB) for interlaminar shear-stress	SB	

Options for Ply Number Optimization
Responses in F06 File

S T R E S S E S I N L A Y E R E D C O M P O S I T E E L E M E N T S (Q U A D 4)

	ELEMENT ID	PLY ID	STRESSES IN FIBER AND MATRIX DIRECTIONS NORMAL-1	NORMAL-2	SHEAR-12	INTER-LAMINAR STRESSES SHEAR XZ-MAT	SHEAR YZ-MAT	PRINCIPAL STRESSES (ZERO SHEAR) ANGLE	MAJOR	MINOR	MAX SHEAR
0	8264	1	1.78751E+01	-1.68306E+01	2.41331E+00	4.82031E-02	-1.05478E-01	3.96	1.80421E+01	-1.69976E+01	1.75198E+01
0	8264	2	-4.22498E+01	-6.36100E+00	1.10039E+01	1.43883E-01	-1.50335E-01	74.24	-3.25576E+00	-4.53551E+01	2.10497E+01
0	8264	3	-2.06818E+01	-9.60743E+00	-1.06974E+01	2.36897E-01	-1.93942E-01	-58.68	-3.09908E+00	-2.71901E+01	1.20455E+01
			σ_1	σ_2	τ_{12}	τ_{xz}	τ_{yz}	θ_p	σ_{max}	σ_{min}	τ_{max}

S T R A I N S I N L A Y E R E D C O M P O S I T E E L E M E N T S (Q U A D 4)

	ELEMENT ID	PLY ID	STRAINS IN FIBER AND MATRIX DIRECTIONS NORMAL-1	NORMAL-2	SHEAR-12	INTER-LAMINAR STRAINS SHEAR XZ-MAT	SHEAR YZ-MAT	PRINCIPAL STRAINS (ZERO SHEAR) ANGLE	MAJOR	MINOR	MAX SHEAR
0	8264	1	-3.81162E-04	1.87582E-03	2.83217E-04	0.0	0.0	86.42	1.88467E-03	-3.90012E-04	2.27468E-03
0	8264	2	6.05720E-04	8.88938E-04	-2.25698E-03	0.0	0.0	-48.58	1.88467E-03	-3.90012E-04	2.27468E-03
0	8264	3	8.88938E-04	6.05720E-04	2.25698E-03	0.0	0.0	41.42	1.88467E-03	-3.90012E-04	2.27468E-03
			ε_1	ε_2	γ_{12}	γ_{xz}	γ_{yz}	θ_p	ε_{max}	ε_{min}	γ_{max}

F A I L U R E I N D I C E S F O R L A Y E R E D C O M P O S I T E E L E M E N T S (Q U A D 4)

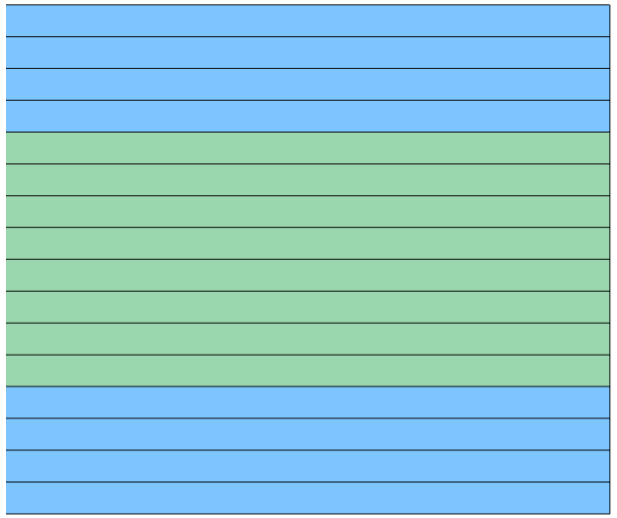
ELEMENT ID	FAILURE THEORY	PLY ID	FP=FAILURE INDEX FOR PLY (DIRECT STRESSES/STRAINS)	FB=FAILURE INDEX FOR BONDING (INTER-LAMINAR STRESSES)	FAILURE INDEX FOR ELEMENT MAX OF FP,FB FOR ALL PLIES	FLAG
8264	HILL	1	0.0226			
				0.0012		
[…]						
		17	0.0668			
				0.0012		
		18	0.2976			
			FP	FB	0.2976	

Balance

1. Ensure the starting composite has both +θ AND -θ plies, e.g. ±45°, ±60°, etc.
2. Use Link Plies in the web app

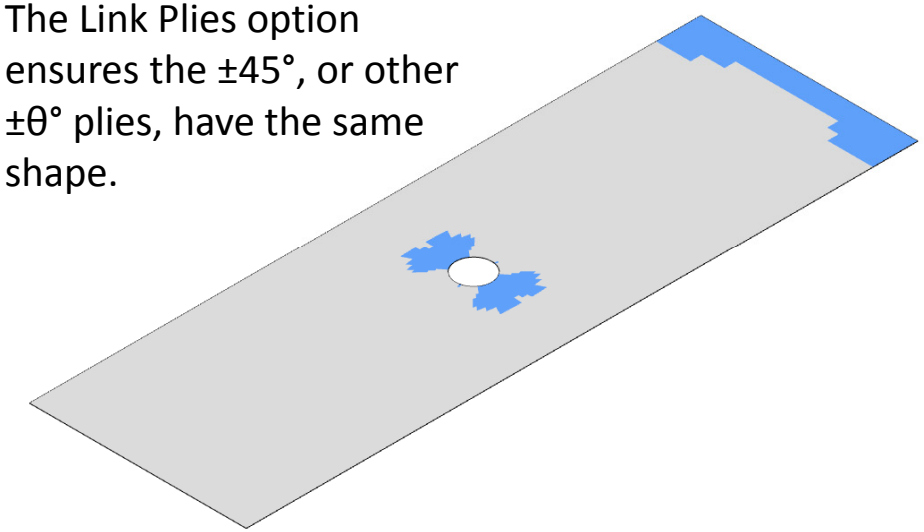
Not Balanced
[45°]

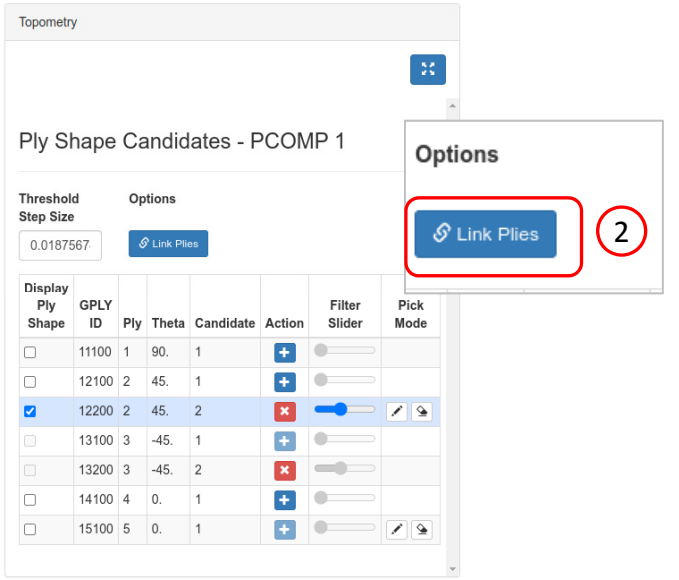
Balanced
[45°/-45°]



1

The Link Plies option ensures the ±45°, or other ±θ° plies, have the same shape.

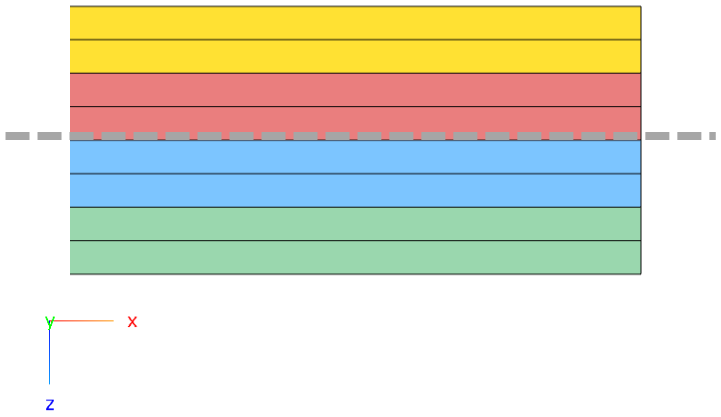




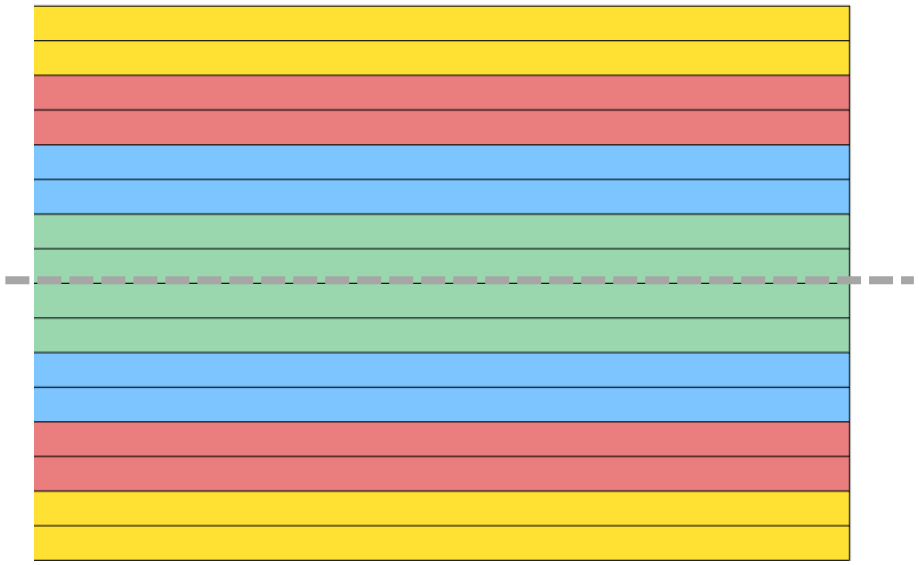
Symmetry

1. Set the laminate option (LAM) to symmetry (SYM)

Asymmetric



Symmetric



Respective PCOMP/PCOMPG Entries

Entry Name

PCOMPG

Laminate Option

SYM 1

Ply Number Optimization Checklist

- Ply Thickness
- Z0 Offset
- % Rule Design
- Total Thickness
- Constraints

Save New Entries

```
$   1   ||   2   ||   3   ||   4   ||   5   ||   6   ||
PCOMPG  2                             90.     HILL
        11100   101     .3755   90.     YES
        12100   101     .3755   45.     YES
        13100   101     .3755   -45.    YES
        14100   101     .3755   0.      YES
        15100   501     3.175   0.      YES
        215100  501     3.175   0.      YES
        214100  101     .3755   0.      YES
        213100  101     .3755   -45.    YES
        212100  101     .3755   45.     YES
        211100  101     .3755   90.     YES
PCOMPG  3                             90.     HILL
        11100   101     .3755   90.     YES
        12100   101     .3755   45.     YES
        12200   101     .3755   45.     YES
        13100   101     .3755   -45.    YES
        13200   101     .3755   -45.    YES
        14100   101     .3755   0.      YES
        15100   501     3.175   0.      YES
        215100  501     3.175   0.      YES
        214100  101     .3755   0.      YES
        213200  101     .3755   -45.    YES
```

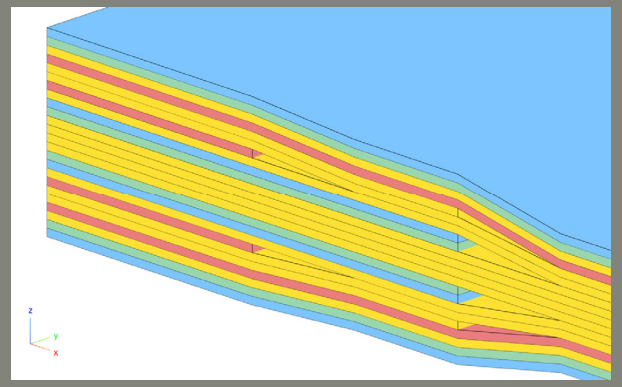
0.	
90.	
45.	
-45.	

Offset to Outer Mold Line

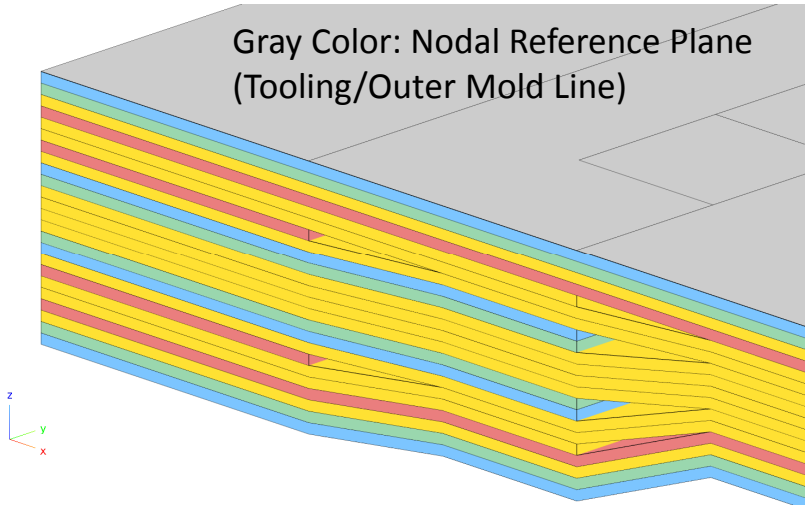
Different manufacturing methods require different offsets.

1. Use Z0 Offset Relationship to ensure the composite is offset to reflect the manufacturing tooling, e.g. outer mold line

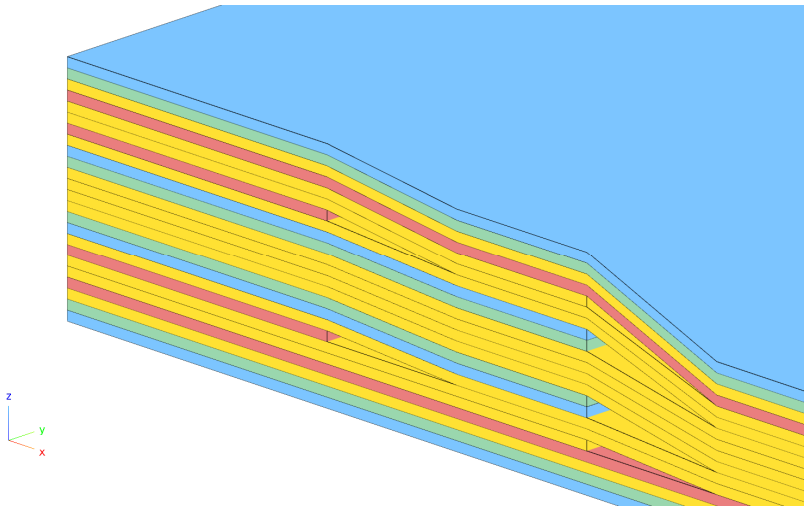
Offset Default (No Offset)

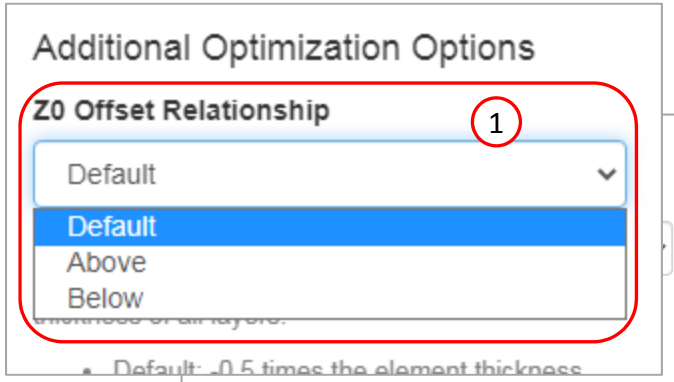


Offset Bottom



Offset Top





0.	
90.	
45.	
-45.	

% Rule Design

Theta [θ]	% Lower Allowed Limit	% Upper Allowed Limit
-45.	Lower	Upper
0.	Lower	Upper
45.	Lower	Upper
90.	Lower	Upper

Total Thickness

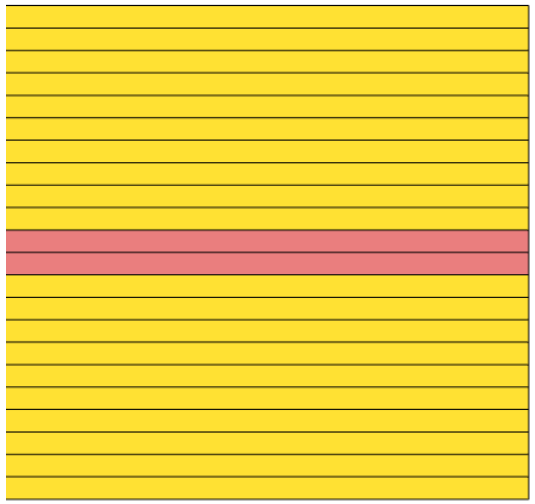
Lower Allowed Limit	Upper Allowed Limit
Lower	Upper

10% Design Rule

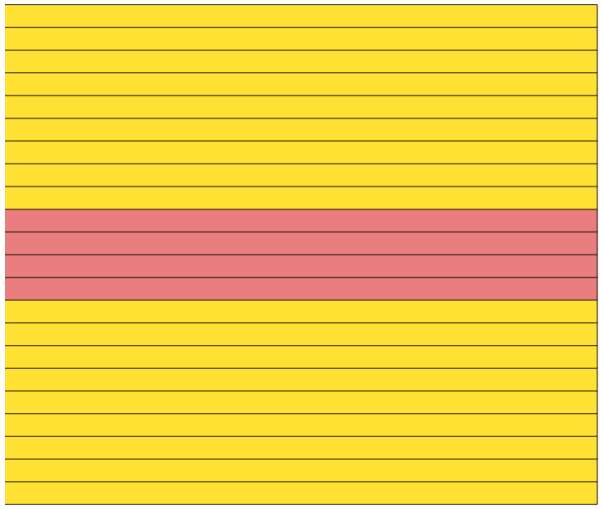
During optimization, there may be too few plies of a particular angle, e.g. 90°

1. Use % Rule Design to put a lower bound on the percentage of specific ply angles

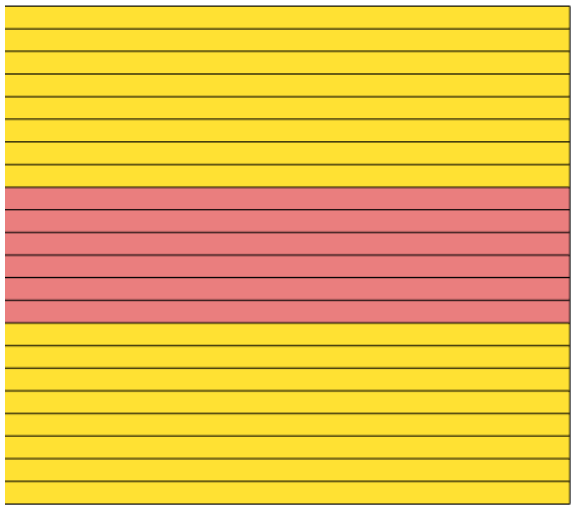
No percent constraint



Minimum of 10% of plies are 90°



Minimum 20% of plies are 90°



2 plies / 22 plies x 100 = 9%

4 plies / 22 plies x 100 = 18%

6 plies / 22 plies x 100 = 27%

Additional Optimization Options

Z0 Offset Relationship

Default

Distance from the reference plane to the botto surface. The element thickness is the total thickness of all layers.

- Default: -0.5 times the element thickne
- Above: 1.0 times the element thickness
- Below: -1.0 times the element thicknes

% Rule Design

Theta [θ]	% Lower Allowed Limit	% Upper Allowed Limit
-45.	Lower	Upper
0.	Lower	Upper
45.	Lower	Upper
90.	10.	Upper

1

0.

90.

Thickness

r Allowed Limit | Upper Allowed Limit

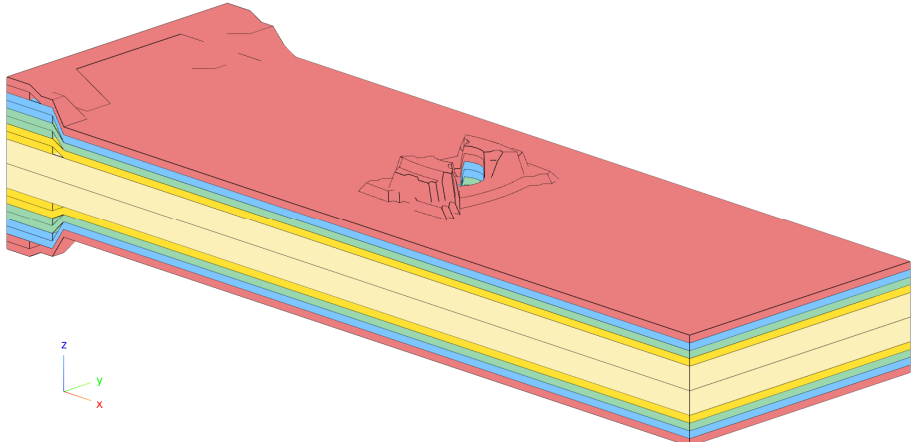
Upper

Total Thickness

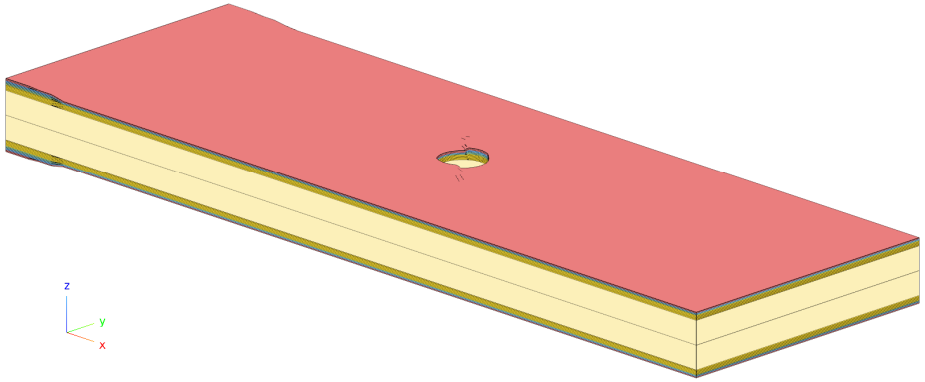
The optimizer may inadvertently produce a composite that is very thick.

1. Use the Total Thickness option to limit the total thickness of the composite

No Total Thickness Constraint



With Total Thickness Constraint



Additional Optimization Options

Z0 Offset Relationship

Default

Distance from the reference plane to the bottom surface. The element thickness is the total thickness of all layers.

- Default: -0.5 times the element thickness
- Above: 1.0 times the element thickness
- Below: -1.0 times the element thickness

% Rule Design

Theta [θ]	% Lower Allowed Limit	
-45.	Lower	
0.	Lower	
45.	Lower	Upper
90.	Lower	Upper

Total Thickness

Lower Allowed Limit	Upper Allowed Limit
Lower	8.85 (1)

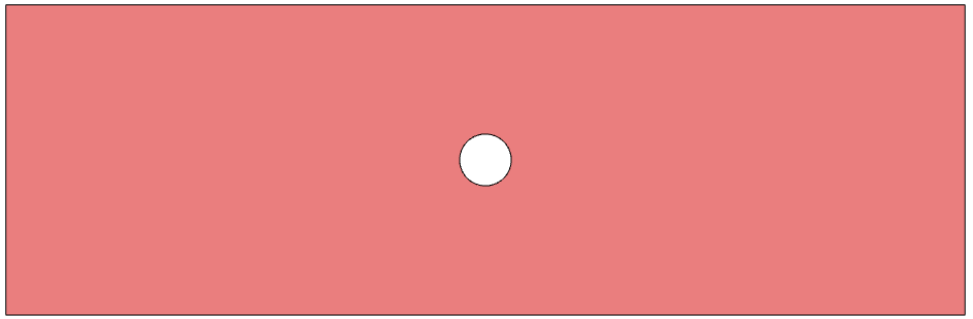
GPLY ID Numbering Convention (sPLC000)

GPLY ID Numbering Convention (sPLC000)

- When configuring ply shapes, the original PCOMP entry will be replaced by multiple PCOMPG entries. The original PCOMP entry is said to be the parent PCOMP and the new PCOMPG entries are said to be the child PCOMPG entries.
- A ply numbering convention is used by the web app to help identify the origin of the various new plies.

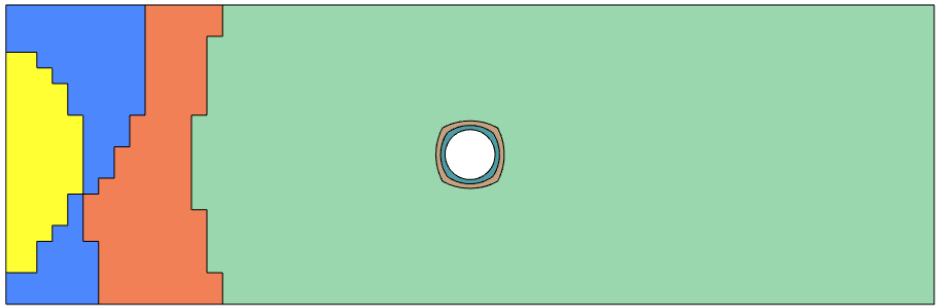
Parent PCOMP

PCOMP	1



```
PCOMP      8                                    90.
           101       .3755     90.       YES
           101       .3755     45.       YES
           101       .3755     -45.      YES
           101       .3755     0.        YES
           501       3.175     0.        YES
```

Child PCOMPGs



PCOMPG	2
PCOMPG	3
PCOMPG	4
PCOMPG	5
PCOMPG	6
PCOMPG	7

```
PCOMPG   2                                    90.       HILL
         111000   101      1.00000 90.       YES
         121000   101      1.00000 45.       YES
         131000   101      1.00000 -45.      YES
         141000   101      1.00000 0.        YES
         151000   501      3.175   0.        YES
         2151000  501      3.175   0.        YES
         2141000  101      1.00000 0.        YES
         2131000  101      1.00000 -45.      YES
         2121000  101      1.00000 45.       YES
         2111000  101      1.00000 90.       YES
PCOMPG   3                                    90.       HILL
         111000   101      1.00000 90.       YES
         152000   101      1.00000 90.       YES
         121000   101      1.00000 45.       YES
         162000   101      1.00000 45.       YES
         131000   101      1.00000 -45.      YES
         132000   101      1.00000 -45.      YES
[…]
```

GPLY ID Numbering Convention (sPLC000)

Each ply shape candidate is assigned a GPLY ID formatted in a special numbering convention. This formatted GPLY ID is read from right to left.

- The last 3 digits 000 is a place holder used by the ply number optimization. After ply number optimization, the 3 digits 000 are replaced by 001, 002, 003, etc. and will depend on the number of plies determined by the ply number optimization.
- The next digit C indicates the candidate number of that ply shape. The Viewer web app is used to construct multiple ply shape candidates.
- The digit L indicates the layer in the original parent PCOMP.
- The digit P indicates the ID of the original parent PCOMP entry. If the original ID is long, for example 1008, the ID is reduced to a single digit.
- A leading digit of 2 indicates the ply is a mirror ply and is used when the composite is symmetric.

For example, GPLY ID 141000 indicates the ply shape candidate was constructed based on a parent PCOMP ID=1 AND the ply shape was constructed based on the model.ply0004 file (layer 4 of the parent PCOMP).

Parent PCOMP

```
PCOMP     1                          90.      HILL                    SYM
          101      .3755     90.      YES     Layer 1
          101      .3755     45.      YES     Layer 2
          101      .3755     -45.     YES     Layer 3
          101      .3755     0.       YES     Layer 4
          501      3.175     0.       YES     Layer 5
```

Child PCOMPG

```
PCOMPG    2                          90.      HILL
          111000   101      1.00000  90.      YES
          121000   101      1.00000  45.      YES
          131000   101      1.00000  -45.     YES
          141000   101      1.00000  0.       YES
          151000   501      3.175    0.       YES
          2151000  501      3.175    0.       YES
          2141000  101      1.00000  0.       YES
          2131000  101      1.00000  -45.     YES
          2121000  101      1.00000  45.      YES
          2111000  101      1.00000  90.      YES
```

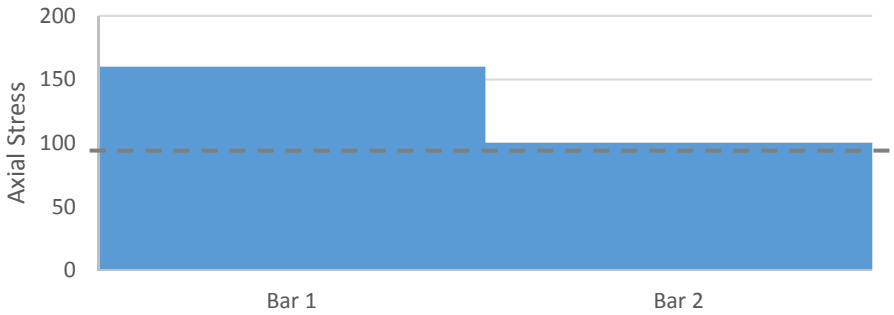
Ply Numbering Convention (sPLC000)

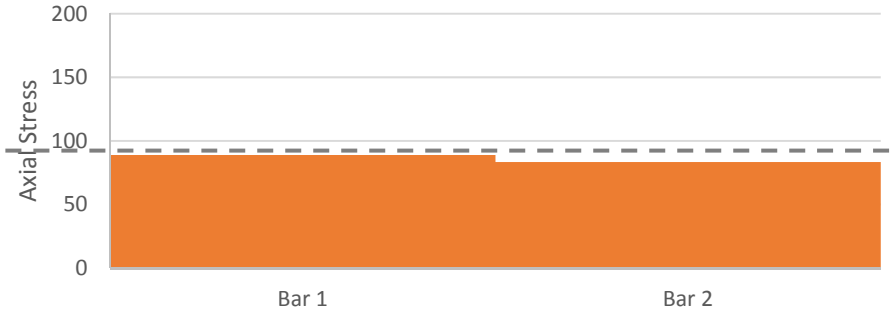
```
          GPLYID=2141000
                2 1 4 1 000
Symmetry Flag <| | | | |
 PCOMP ID P   <--| | | |
    LAYER L   <----| | |
Candidate C   <------| |
  ith Ply 000 <--------|
```

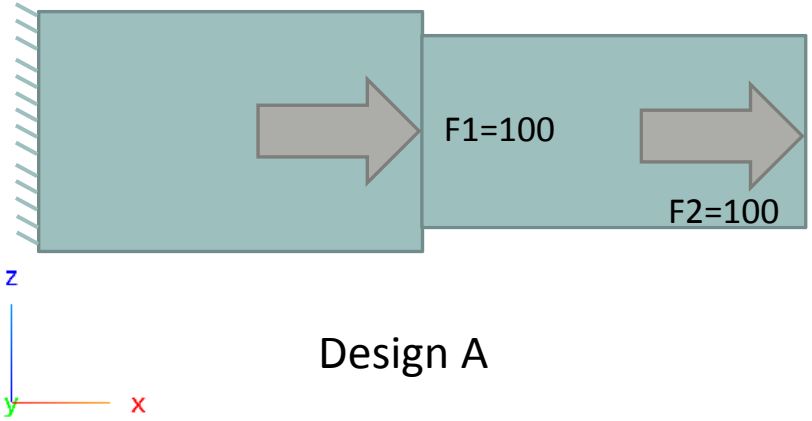
Optimizing Composite Ply Shapes and Numbers for Uniaxial Loading

Axial Loaded Members

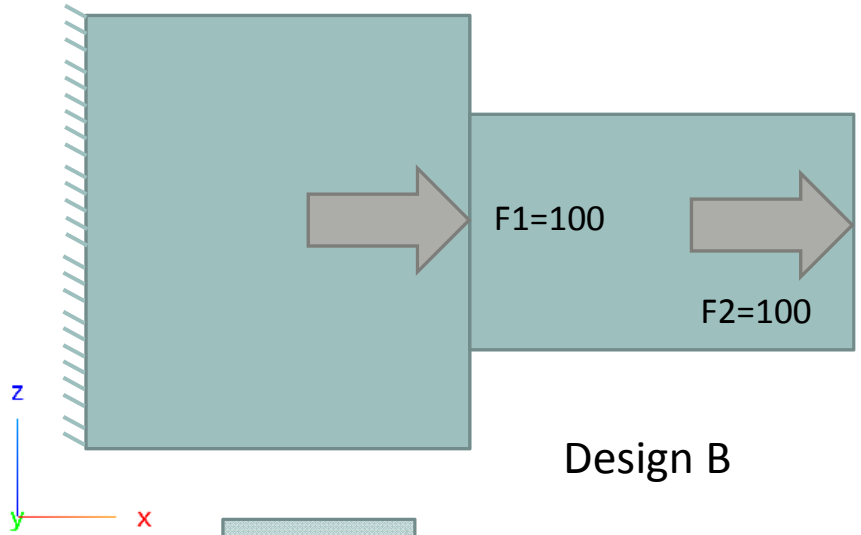
1. Consider designs A and B subjected to the indicated loading. The maximum allowed axial stress is 90. The material is linear isotropic and homogenous.
2. Design A exceeds the allowed axial stress of 90.
3. The cross sections are adjusted in design B such that the axial stress is less than 90. Design B satisfies the axial stress limit. For design B, the cross section is expanded by adding strips of area, in thickness increments of 0.1, to the height of the cross section.
    - For a laminated composite with constraints on ply stress, ply strain or failure index, a similar approach may be adopted to minimize the weight while satisfying constraints.



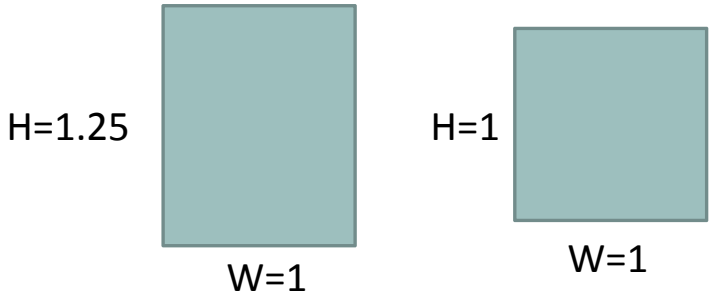


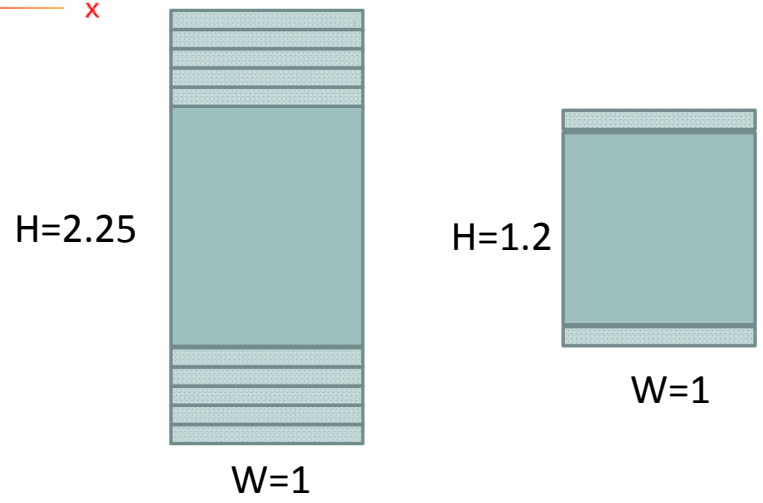


Design A



Design B

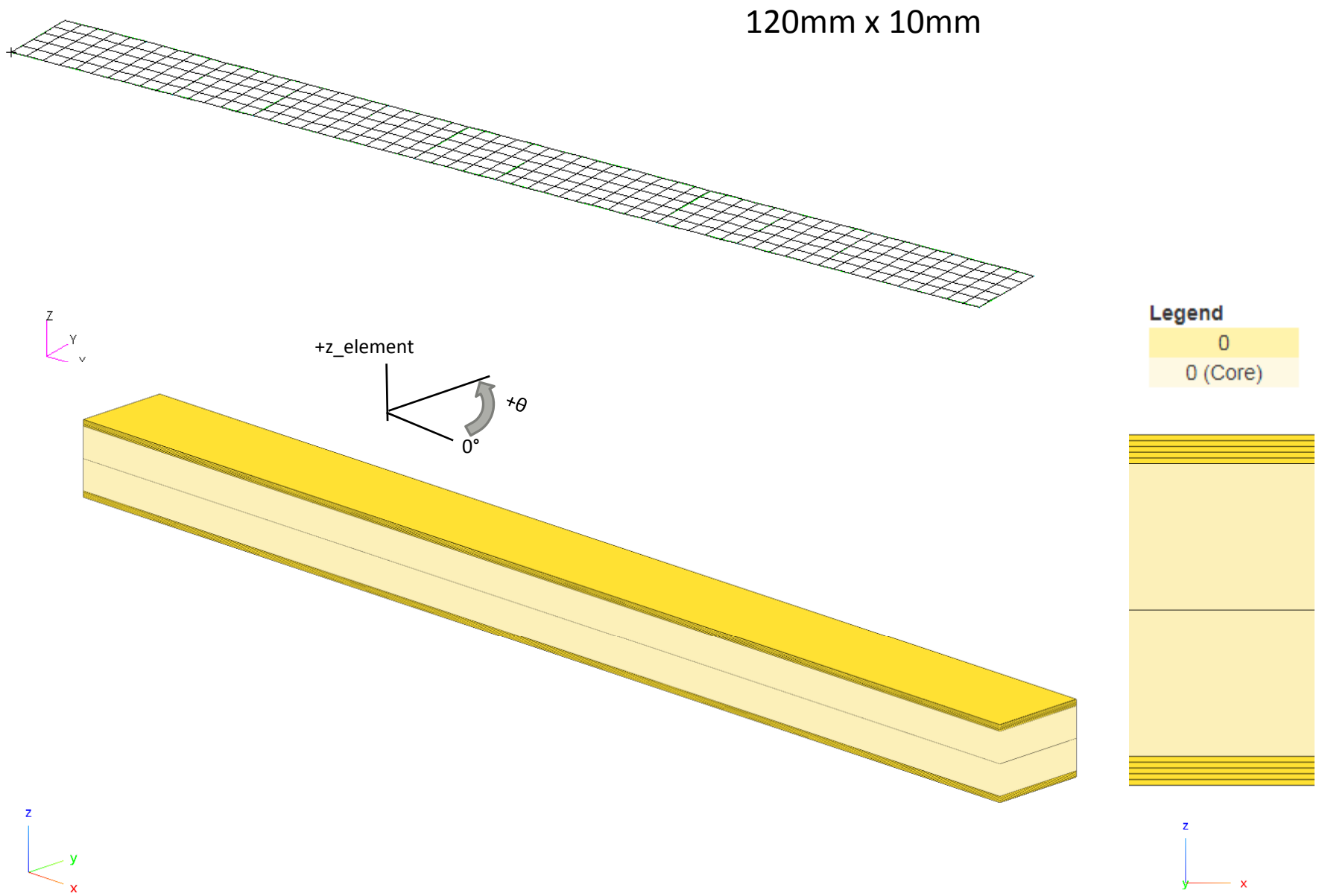




Composite Analysis Model

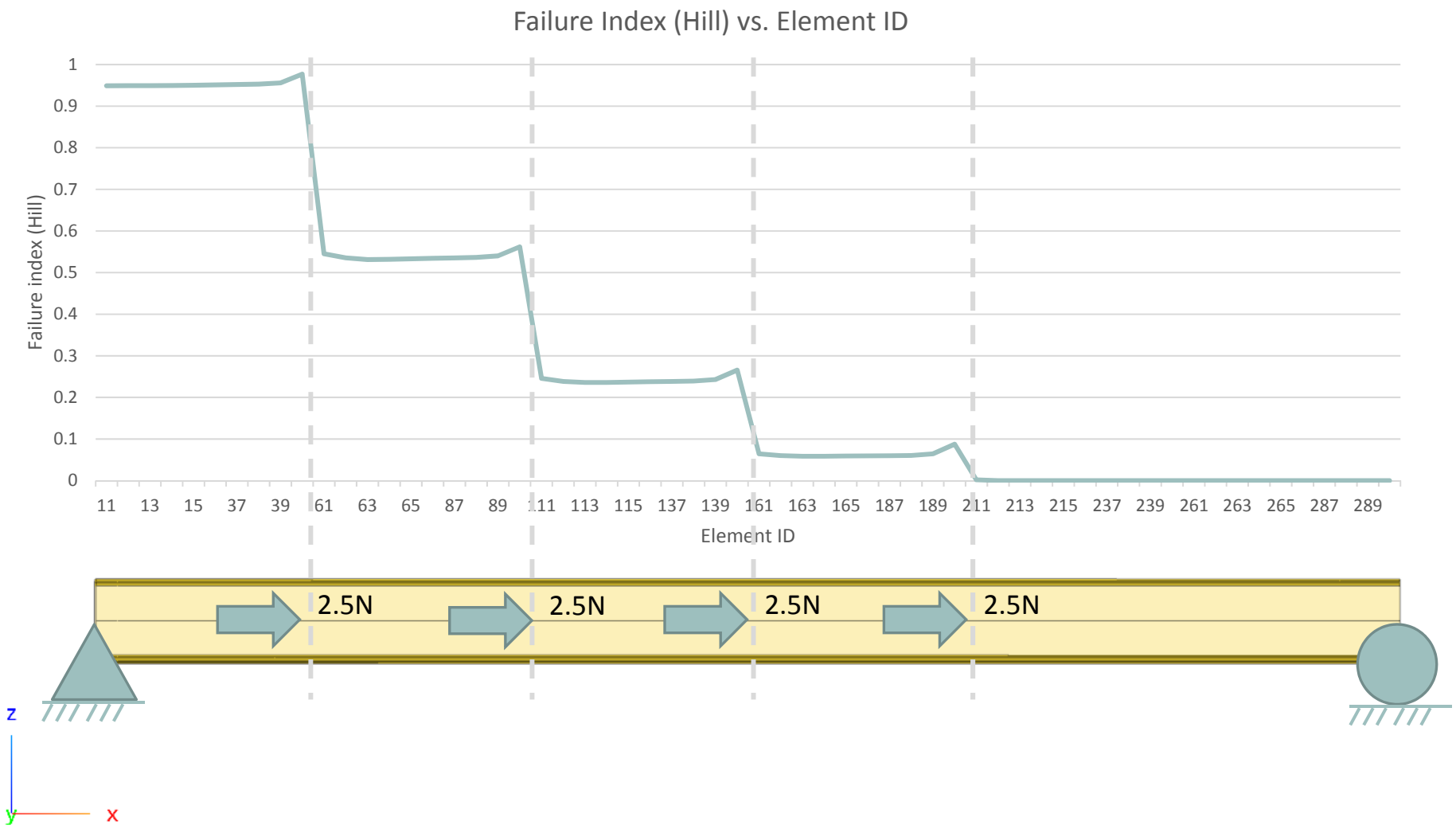
1. Consider this 120mmx10mm composite strip.
2. The ply shapes of the 0° plies will be optimized to minimize weight and satisfy failure index (Hill) constraints. The core is left untouched.

The core is 6.35mm thick and the plies are .125mm thick.



Composite Analysis Model

1. The composite strip is subjected to axial loads.
2. The maximum failure index for all plies is mapped along the length of the strip.

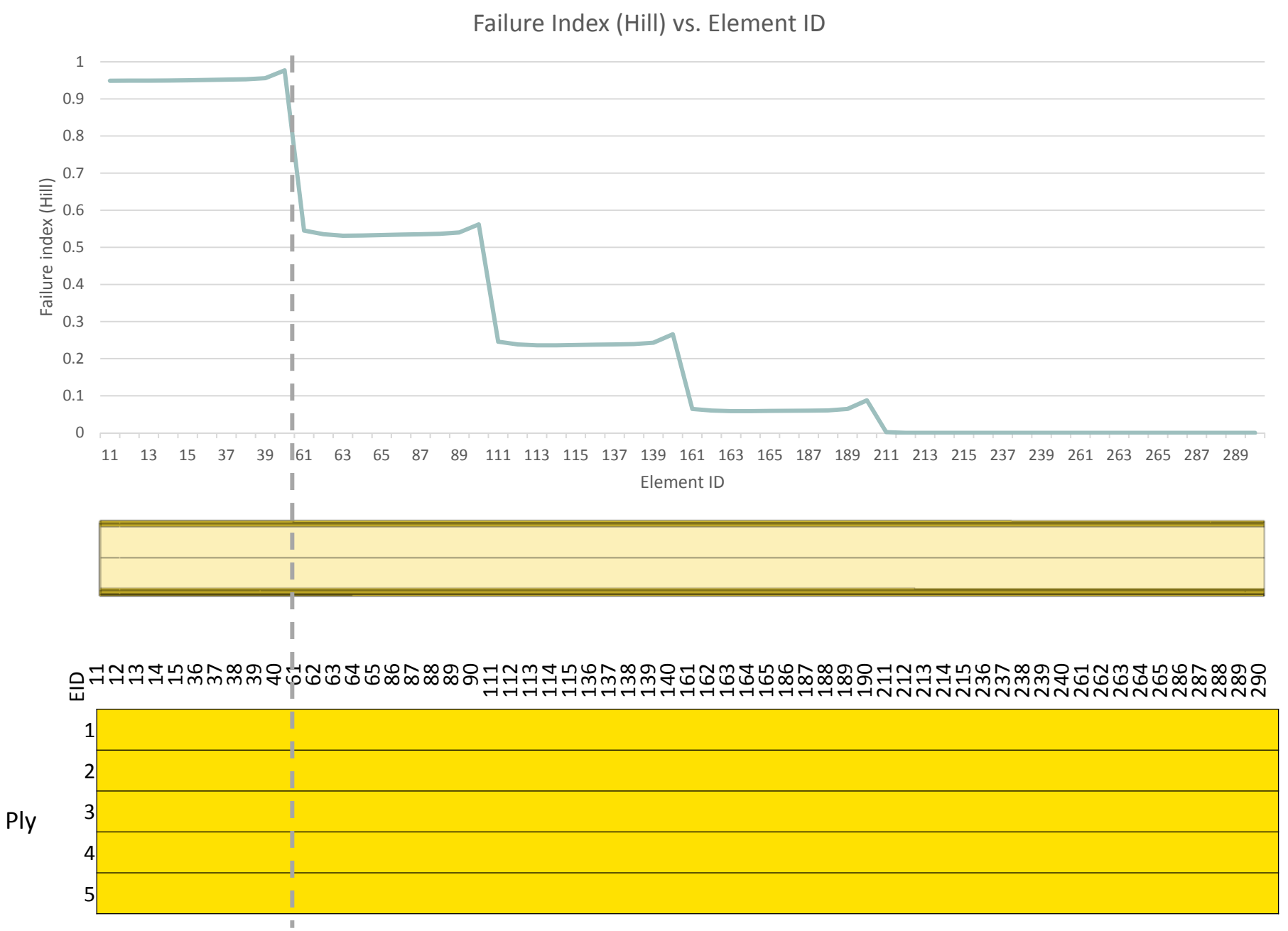


Inspection of Failure Indices

1. It is determined that 10 continuous plies yields a composite that satisfies a maximum failure index of 1.0. The top of the composite has 5 plies and the bottom has 5 plies. Only 5 piles are depicted.

Throughout this example, the maximum failure index of all plies for element i, where i is 11, 12, 13, …, 289, 290, is plotted along the length of the composite.

- Design Model: 20230505_study_of_ply_number_optimization/0_original/model.bdf

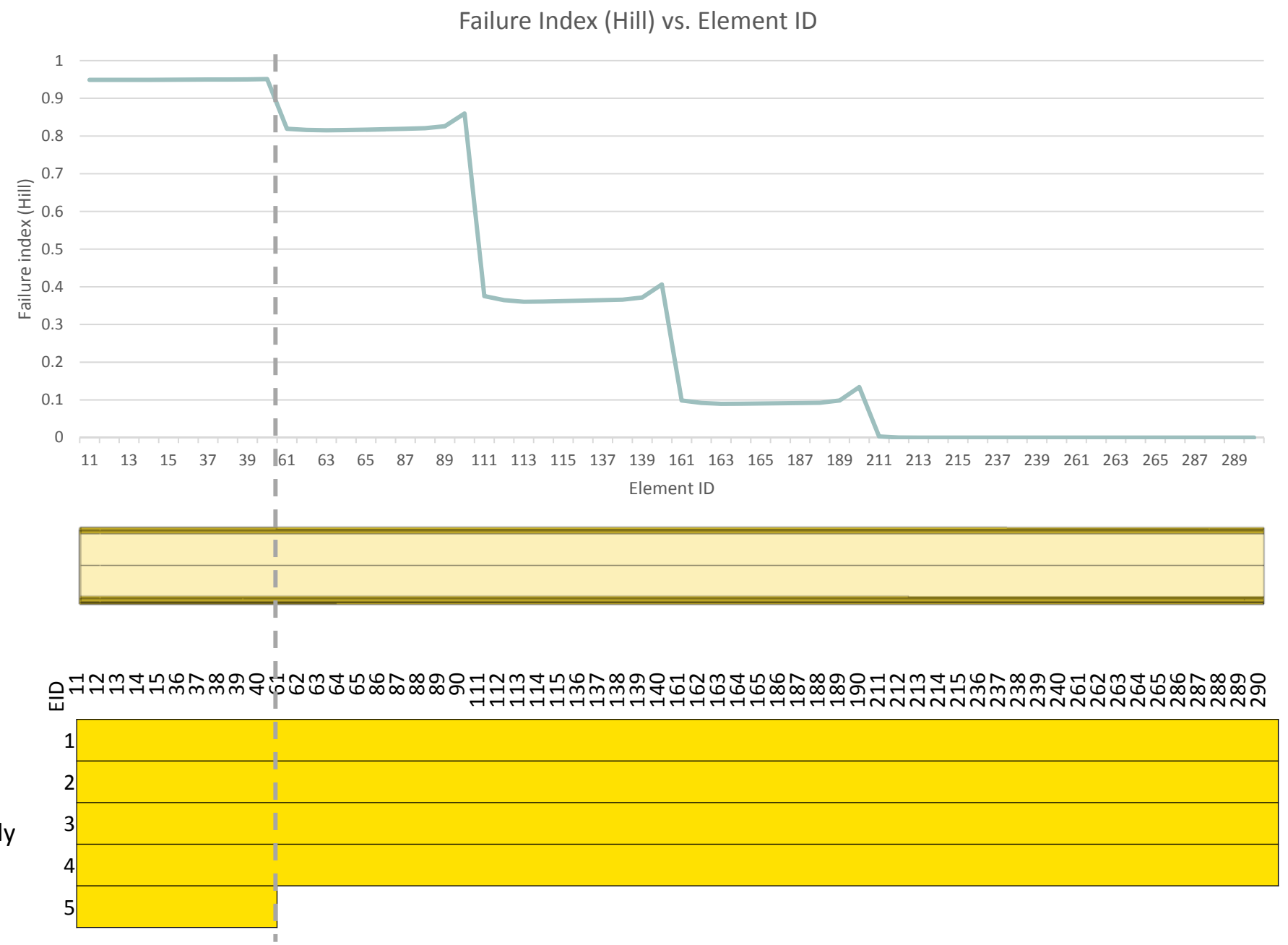


Optimizing One Ply Shape

1. Ply 5 is applied only to elements 11, 12, 13, …, 38, 39, and 40. Ply 5 corresponds to a segment of the failure index plot.
2. For elements 61, 62, 63, …., 289 and 290, only 4 plies are necessary.

Before, 5 plies were needed throughout the composite, but this has been reduced to 4 plies. 5 plies are needed only in the region of high failure index.

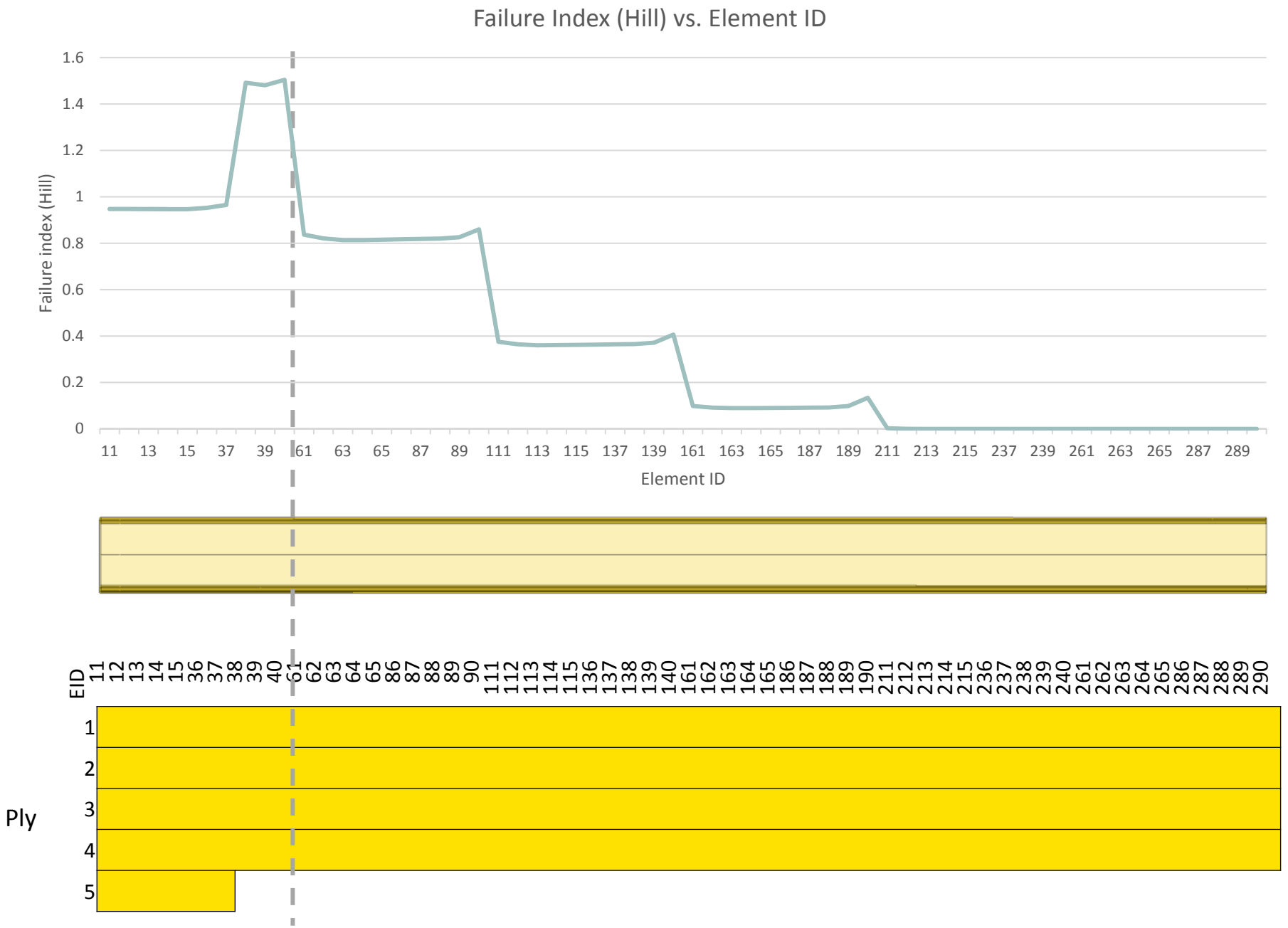
- Design Model: 20230505_study_of_ply_number_optimization/4_ply_number_optimization/workspace_c



Example of a Suboptimal Ply Shape

1. What happens if the ply is too small? Consider ply 5. This ply does not correspond entirely to the failure index plot. The failure index plot now shows the failure index is above 1.0, which is not OK. Ply 5 is insufficient to address the failure index.

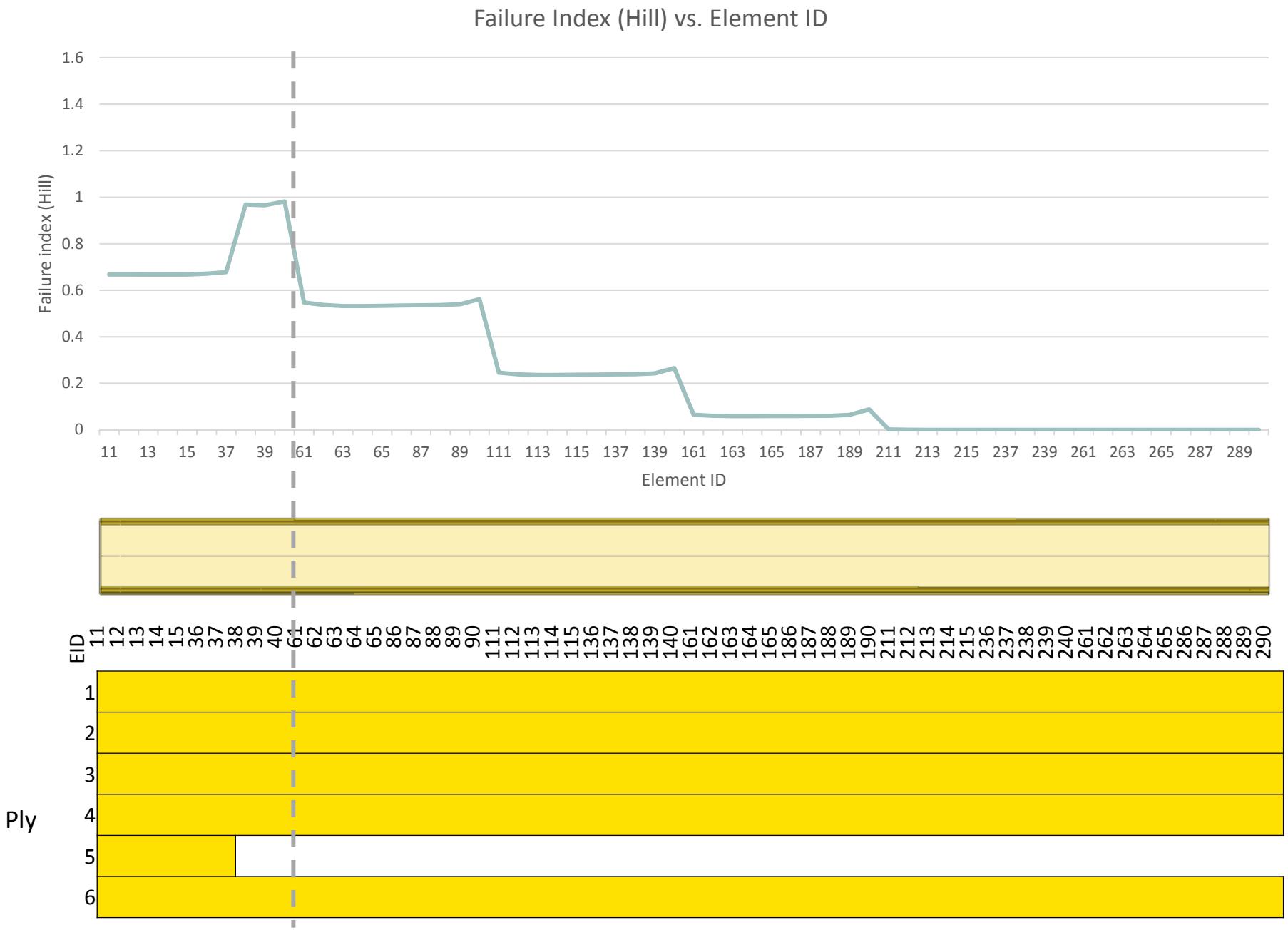
- Design Model: 20230505_study_of_ply_number_optimization/6_ply_number_optimization/workspace_c_b



Example of a Suboptimal Ply Shape, Correction

1. To make up for the insufficient ply 5, a ply number optimization will determine that an additional and fully continuous ply (Ply 6) is necessary. The failure index is now less than 1.0. The composite is now OK.

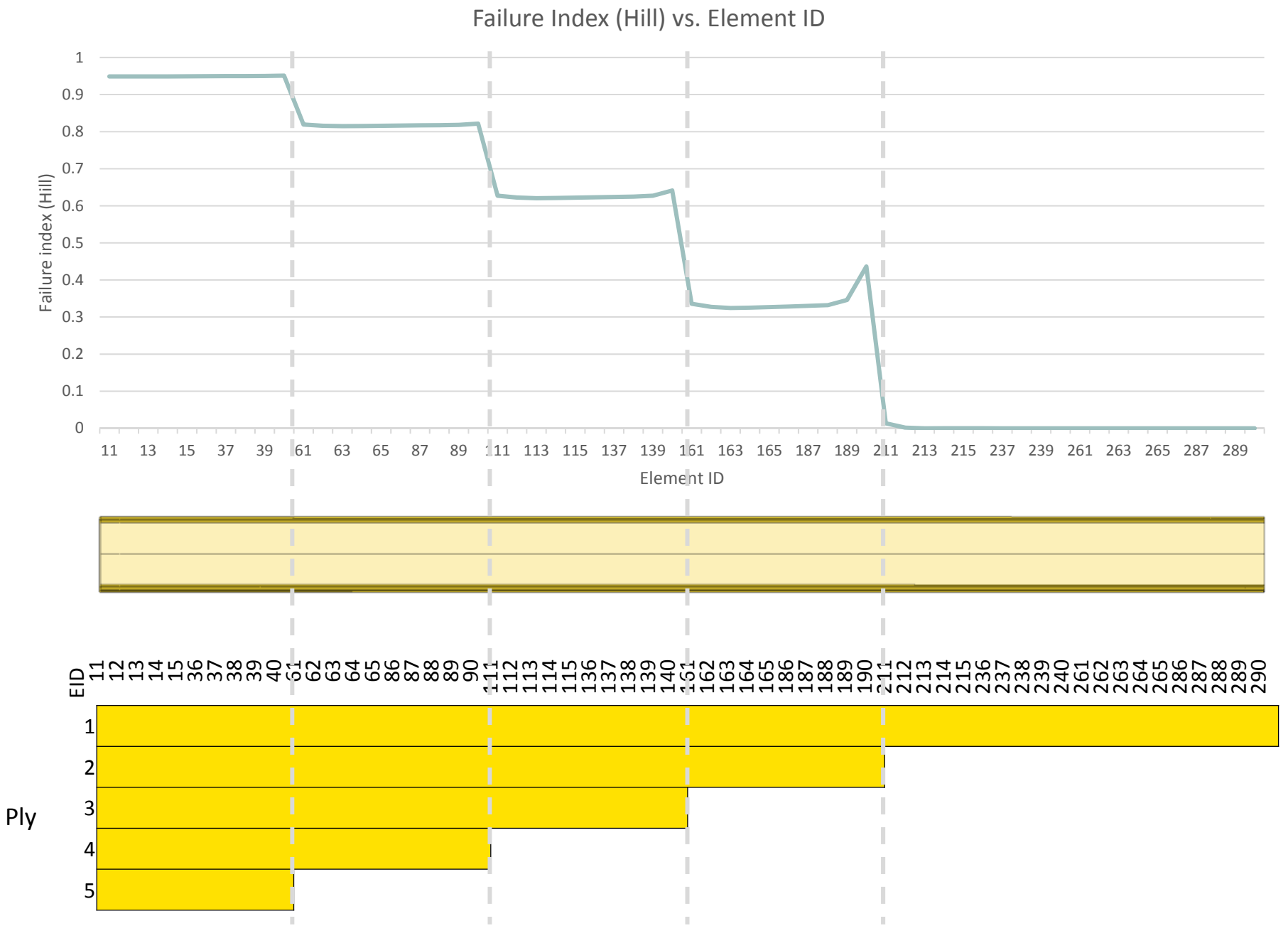
- Design Model: 20230505_study_of_ply_number_optimization/6_ply_number_optimization/workspace_c_c_bad_ply_with_5_good_plies



Optimal Ply Shapes

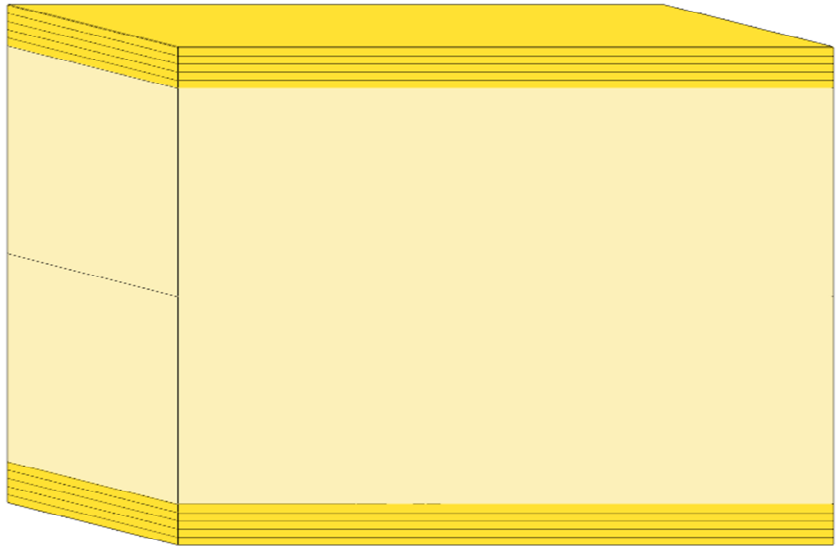
1. Plies 2, 3, 4 and 5 correspond to different ply shapes and correspond to the failure index plot. This design is lightweight compared to the composite with 5 continuous plies.

- Design Model: 20230505_study_of_ply_number_optimization/8_ply_number_optimization/workspace_c

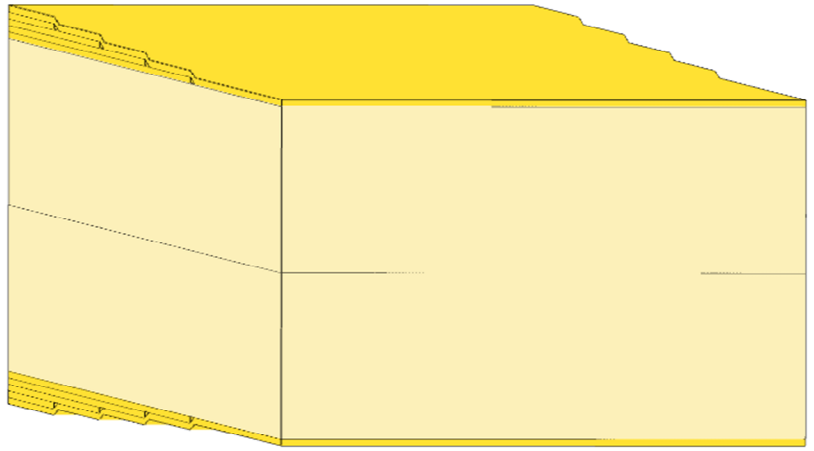


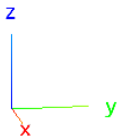
Comparison

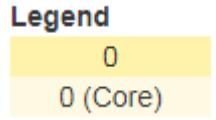
Before
Mass: 4.097700E-06
Max Failure Index: .98 (OK)



After
Mass: 2.932200E-06 28% mass decrease
Max Failure Index: .95 (OK)





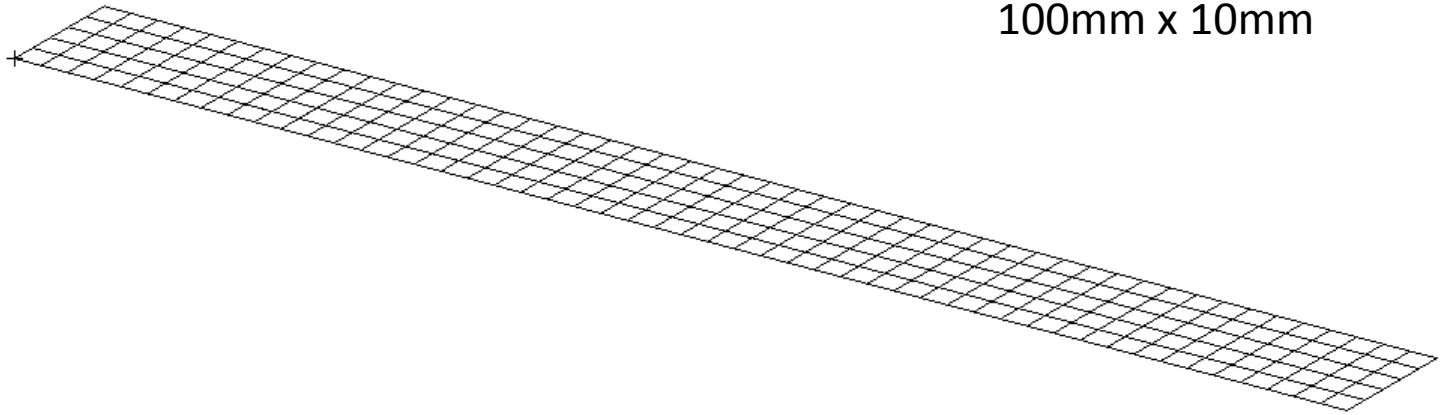


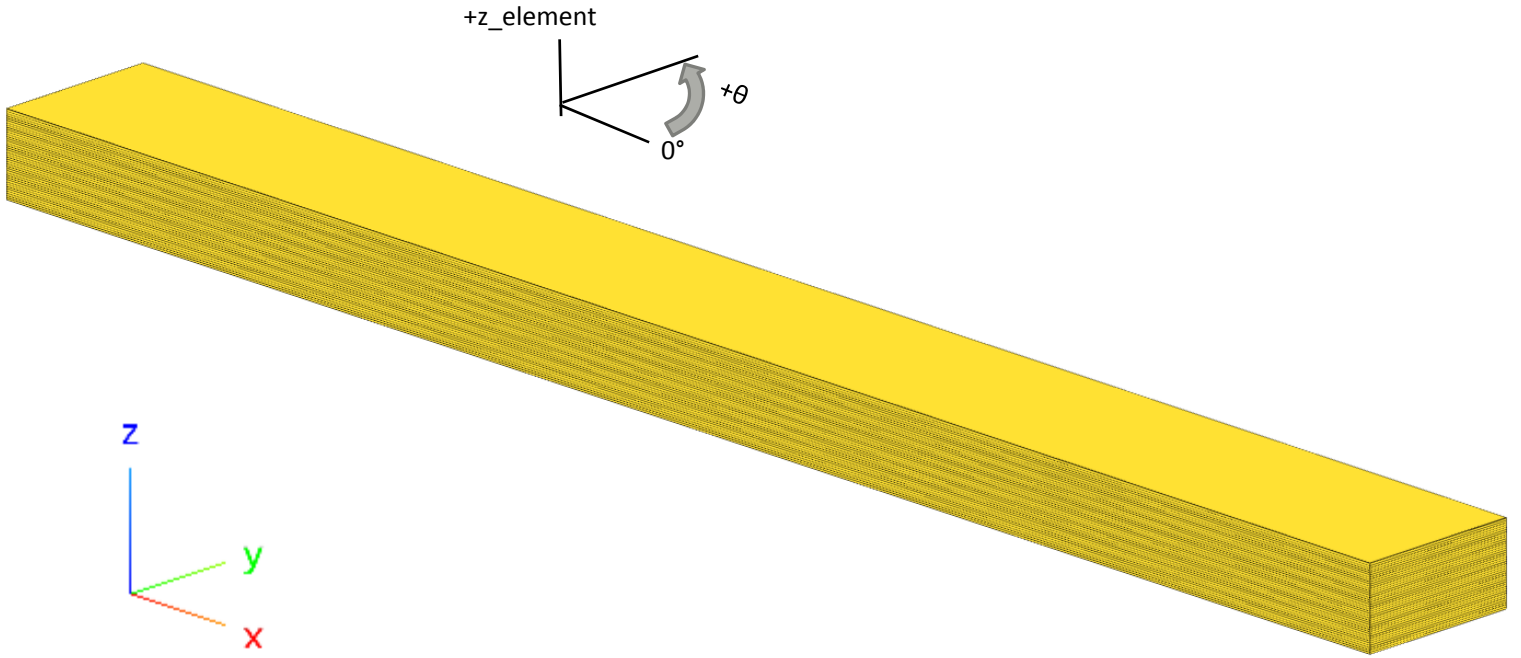
Optimizing Composite Ply Shapes and Numbers for Bending

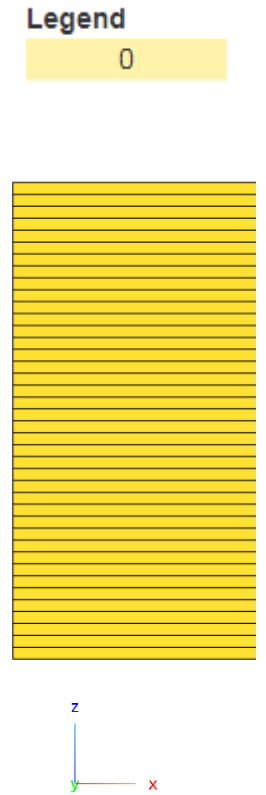
Composite Analysis Model

1. Consider this 100mmx10mm composite strip.
2. The ply shapes of the 0° plies will be optimized to minimize weight and satisfy failure index (Hill) constraints.

The plies are .125mm thick. A total of 40 plies are initially used to satisfy failure index constraints.





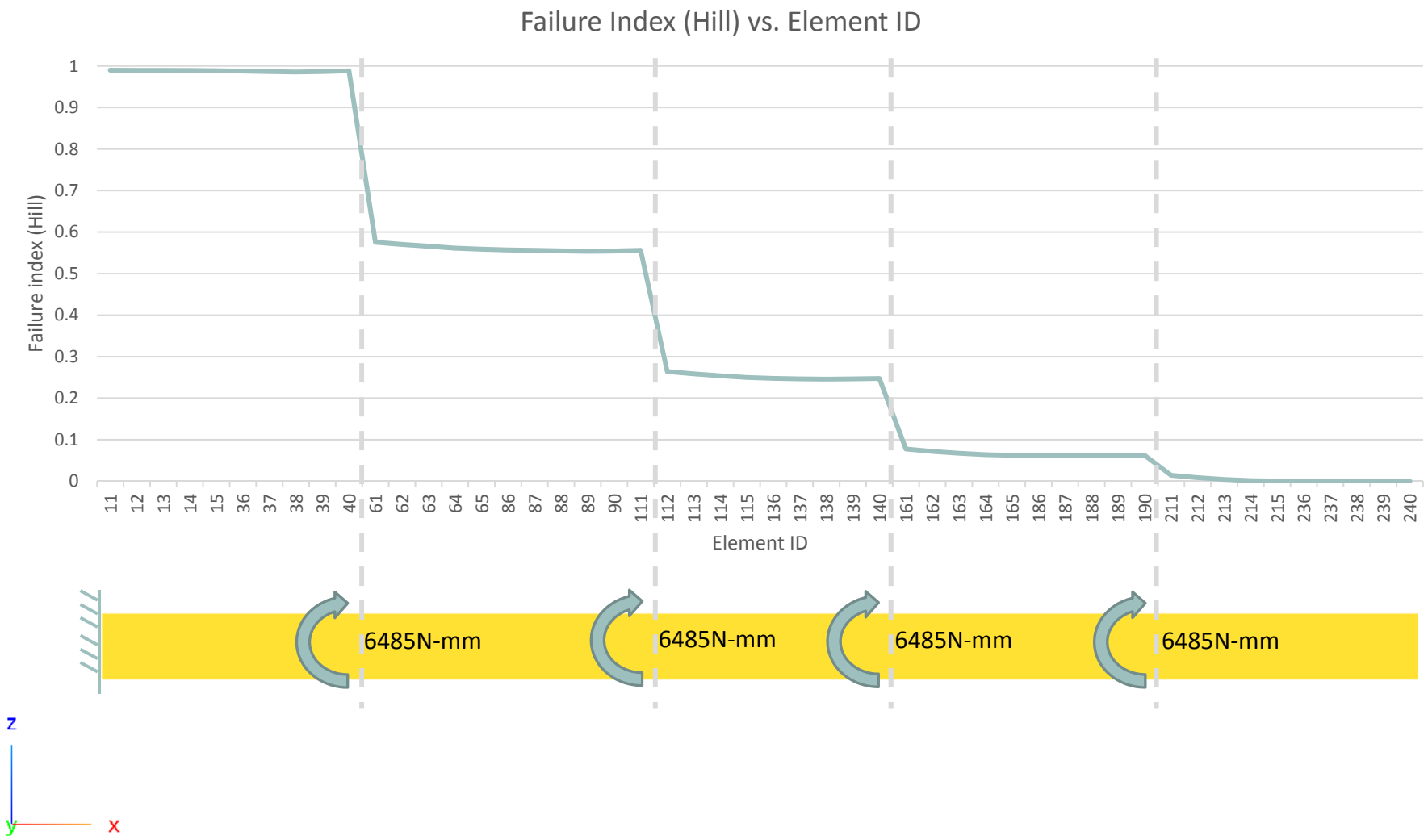


Composite Analysis Model

1. The composite strip is subjected to 4 moments.
2. The maximum failure index occurs at the outer plies. The maximum failure index of plies 1 and 40 are plotted along the length of the strip.

Acknowledgement

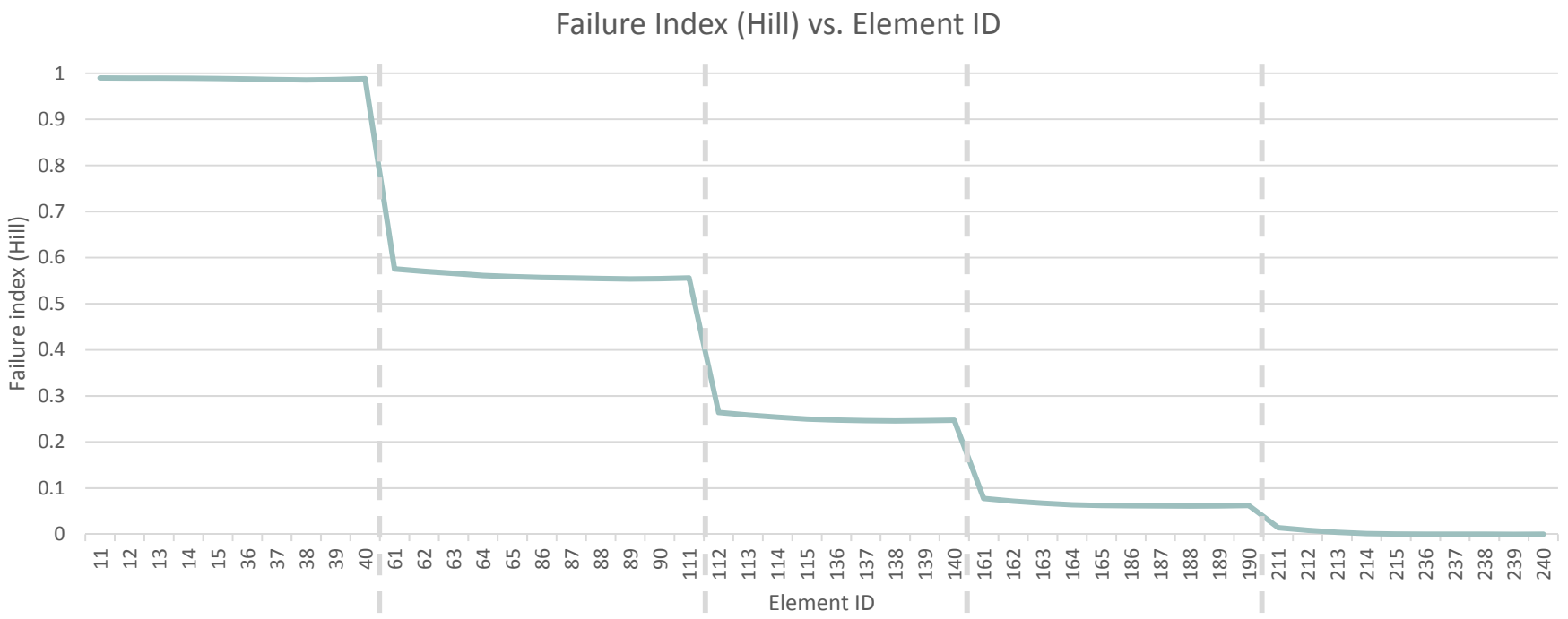
Some observers will realize that the maximum displacement of this model is 30mm, which exceeds the assumption of small deformations, and the moments applied are very large. This is acknowledged and done on purpose to yield maximum failure indices on the range of 0 to 1.0. The goal of this exercise is to demonstrate the procedure and focus on failure indices.

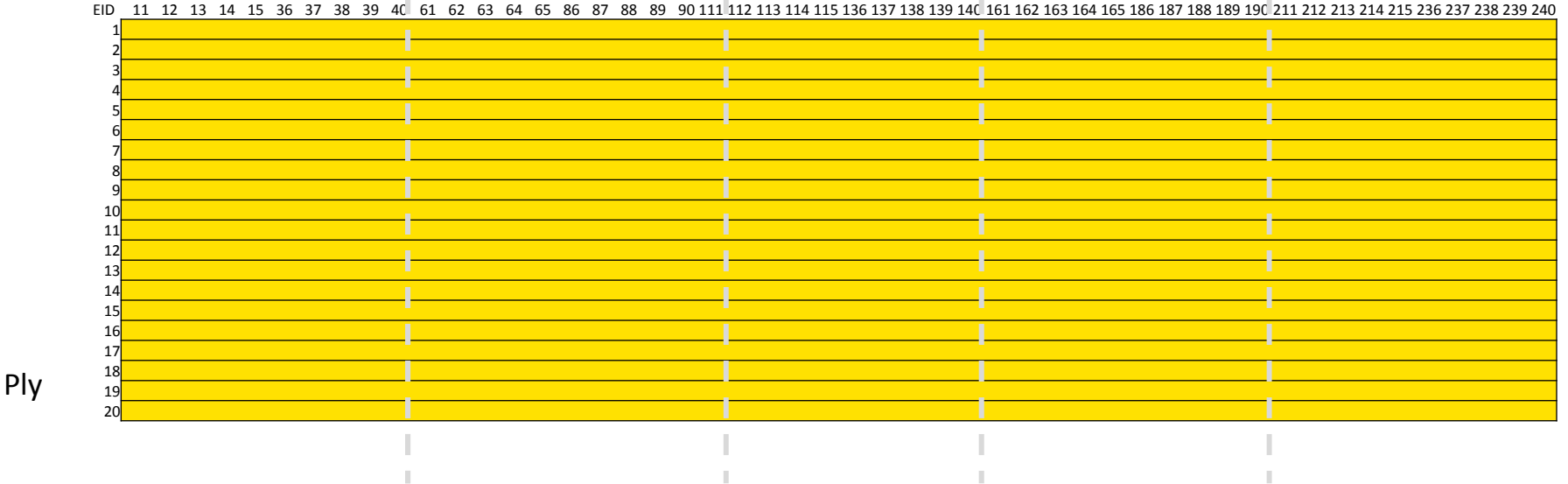


Inspection of Failure Indices

1. It is determined that 40 continuous plies yields a composite that satisfies a maximum failure index of 1.0. The top of the composite has 20 plies and the bottom has 20 plies. Only 20 piles are depicted.

Design Model: 20230506_study_of_ply_number_optimization_bending\2_starting

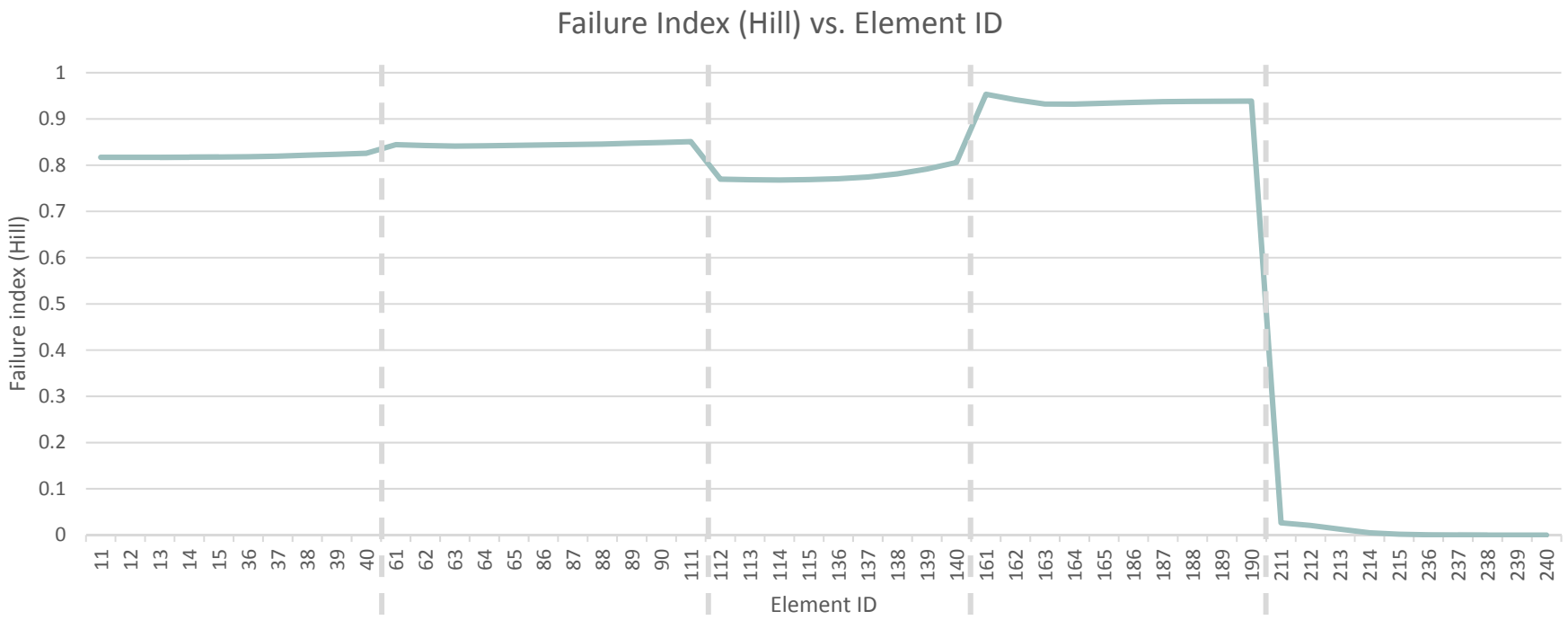


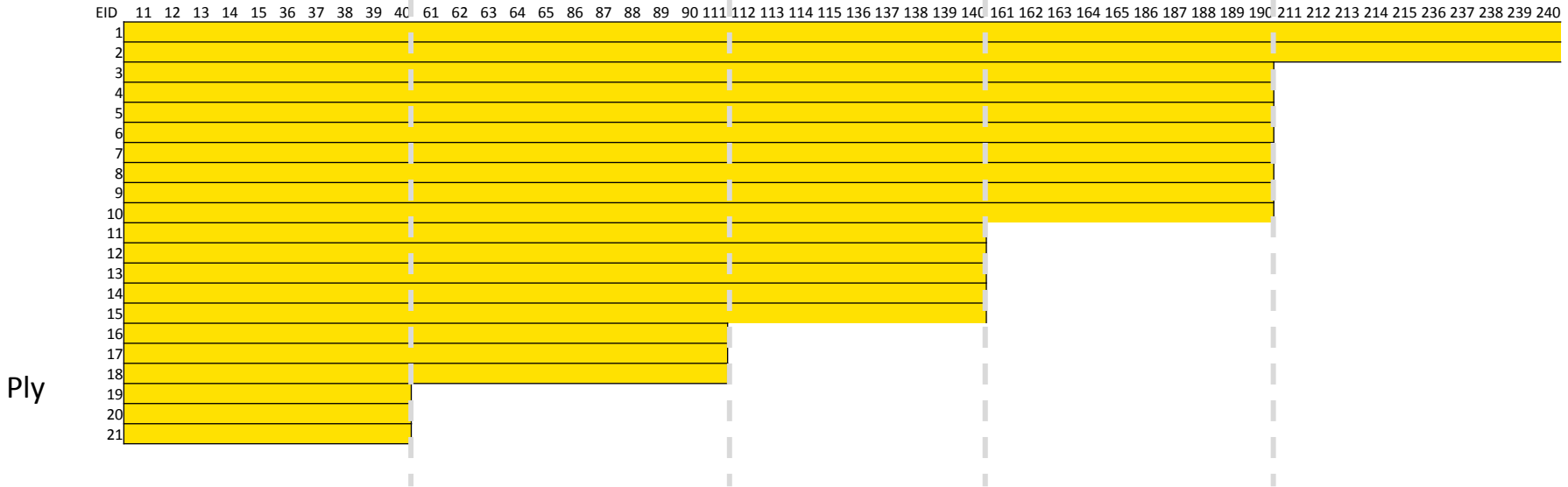


Optimal Ply Shapes

1. Various ply shapes are constructed that correspond to the different steps of the failure index plot. This yields a optimal composite.
2. Notice the failure index is closer to 1.0 throughout the composite and indicates material is being efficiently used.
3. For elements 211, 212, …, 239, 240, the number of plies needed is 2 and the failure index is close to 0. This region is a candidate for removing part of the structure, i.e. introduce a hole or cutout.

Design Model: 20230506_study_of_ply_number_optimization_bending\6_ply_number_optimization\workspace_c





Comparison

1. Mass, Before: 9.990000E-06
2. Mass, After: 5.685975E-06

43% decrease

Max failure index = 9.5323E-01 < 1.0 (OK)

Before

After

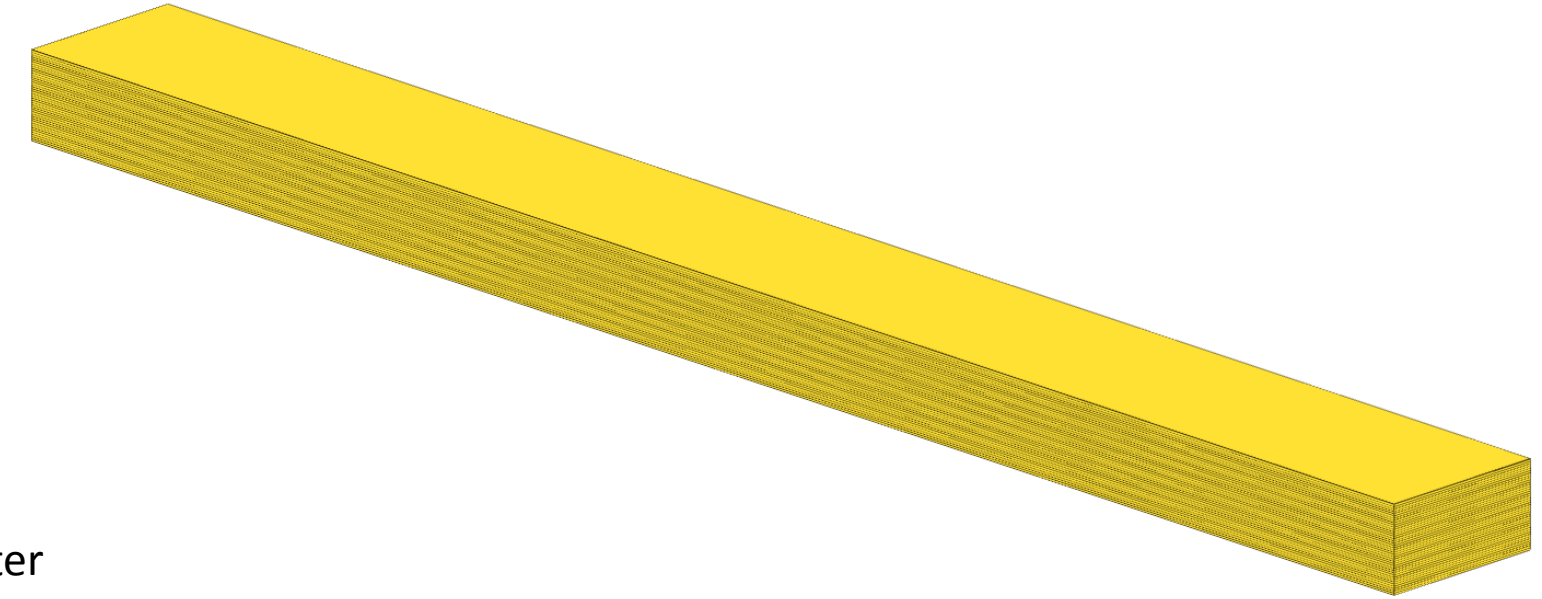
Comparison

1. Mass, Before: 9.990000E-06
2. Mass, After: 5.685975E-06

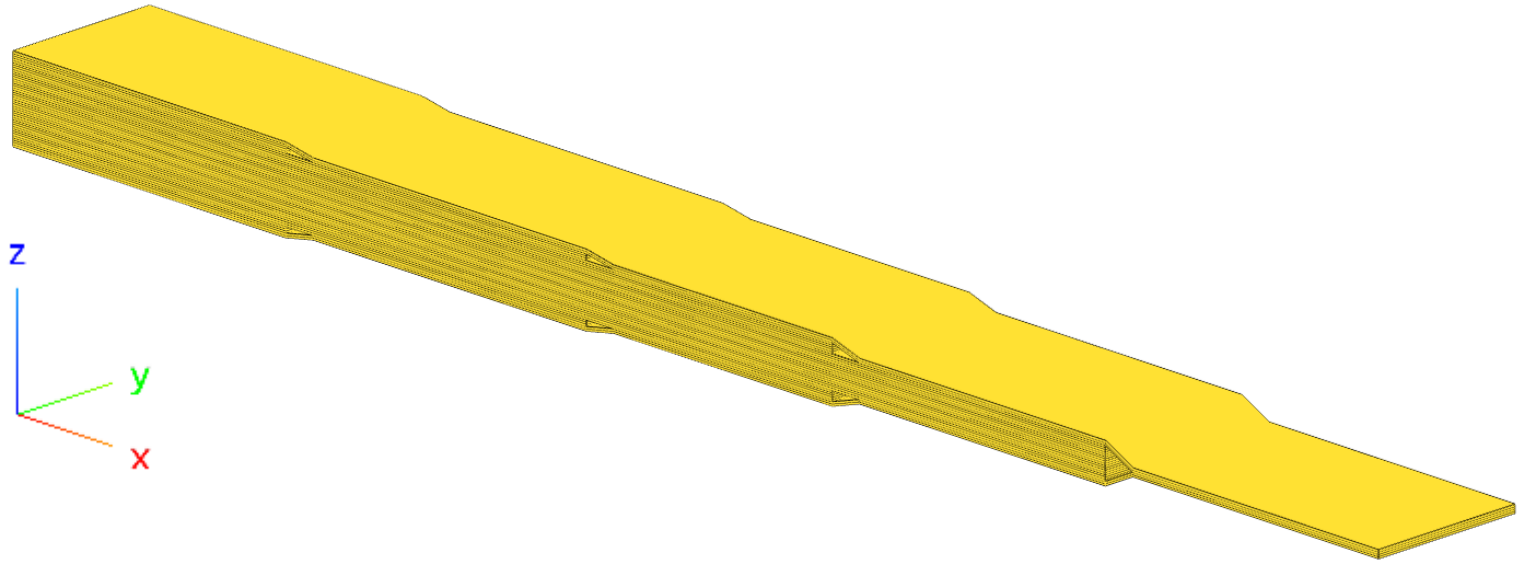
43% decrease

Max failure index = 9.5323E-01 < 1.0 (OK)

Before



After

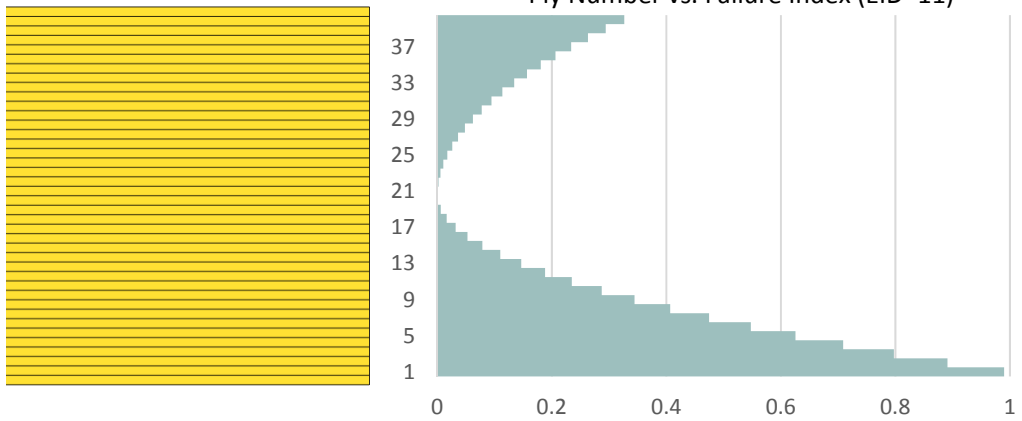


Consideration of PCOMP

1. The SOL 200 Web App supports composite optimization. If bending is a primary focus, the composite configuration C should be used during the optimization process. Configuration C involves a fixed layer 1 and 4. Layer 2 and 3 is allowed to vary during the ply shape and ply number optimization.
    - Why? Consider configuration B, which has 2 layers. The failure index is computed at the midplane of each layer, but the failure index towards the outer fibers may be significantly higher. For configuration A, the failure index of layer 1 is approximately 1.0, but configuration B is reporting a failure index of ~0.2. Configuration C reports a failure index of ~1.0 for ply 1.

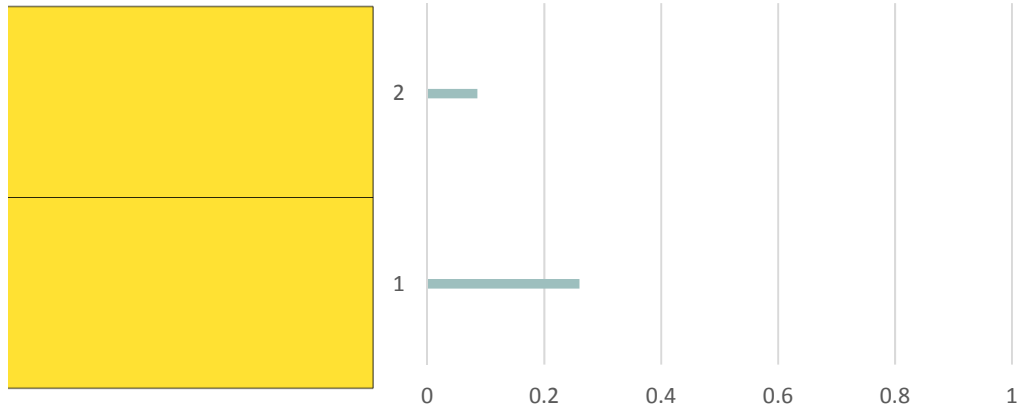
It should be noted that the composite thickness of each configuration is an equal value of 5 mm (40 plies with each ply has a thickness of .125mm). The LAM=SYM option indicates the layers listed on the PCOMP are doubled to create a symmetric composite.

A



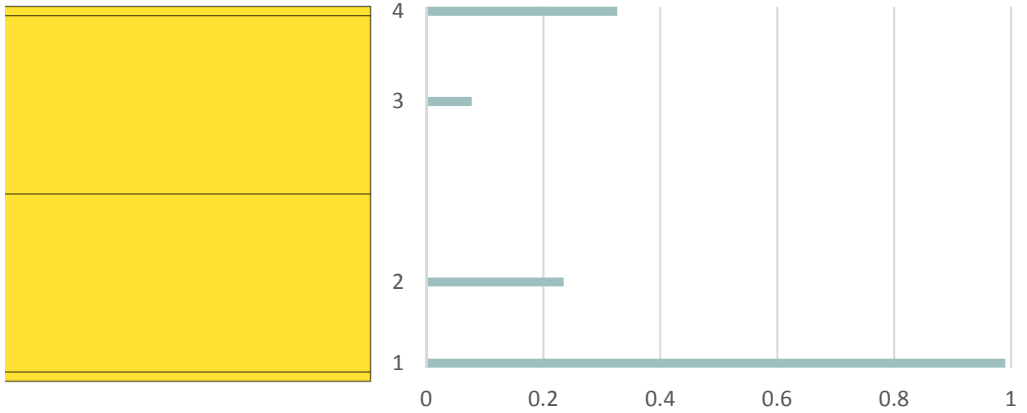

```
PCOMP, 1,,,90., HILL,,SYM
          101     .125     0.       YES
          101     .125     0.       YES
          101     .125     0.       YES
[…] A total of 20 layers are repeated
          101     .125     0.       YES
          101     .125     0.       YES
```

B




```
PCOMP, 1,,,90., HILL,,SYM
          101     2.5      0.       YES
```

C

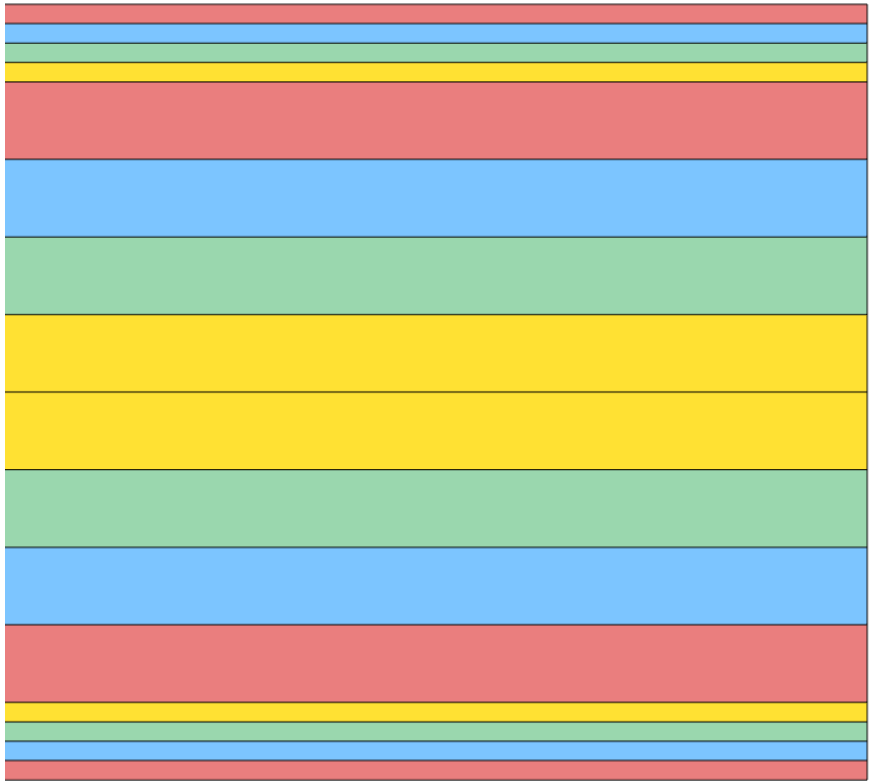


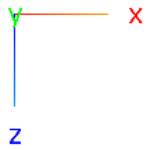

```
PCOMP, 1,,,90., HILL,,SYM
          101     .125     0.       YES
          101    2.375     0.       YES
```

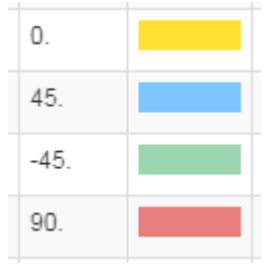
Consideration of PCOMP

1. If other angles, such as 90 or 45 degrees, are considered, fix a few plies on the top and bottom of the composite.

For the example shown, angle 0, 45, -45 and 90 are used. The top has 4 fixed plies (thickness of .125mm), followed by 4 layers with thickness .5mm. The 4 layers with .5mm will vary during the optimization. The plies with .125mm will remain as is during the ply shape and ply number optimization.








```
PCOMP     2                              90.      HILL                    SYM
          101       .125     90.         YES
          101       .125     45.         YES
          101       .125     -45.         YES
          101       .125      0.         YES
          101       .5       90.         YES
          101       .5       45.         YES
          101       .5       -45.         YES
          101       .5       0.          YES
```

These plies remain fixed throughout the entire optimization procedure.

Create TOMVAR entries for the layers and perform ply shape and ply number optimization for these layers only

Monitor the failure index of each layer or constrain the failure index with DRESP1/DCONSTR entries.