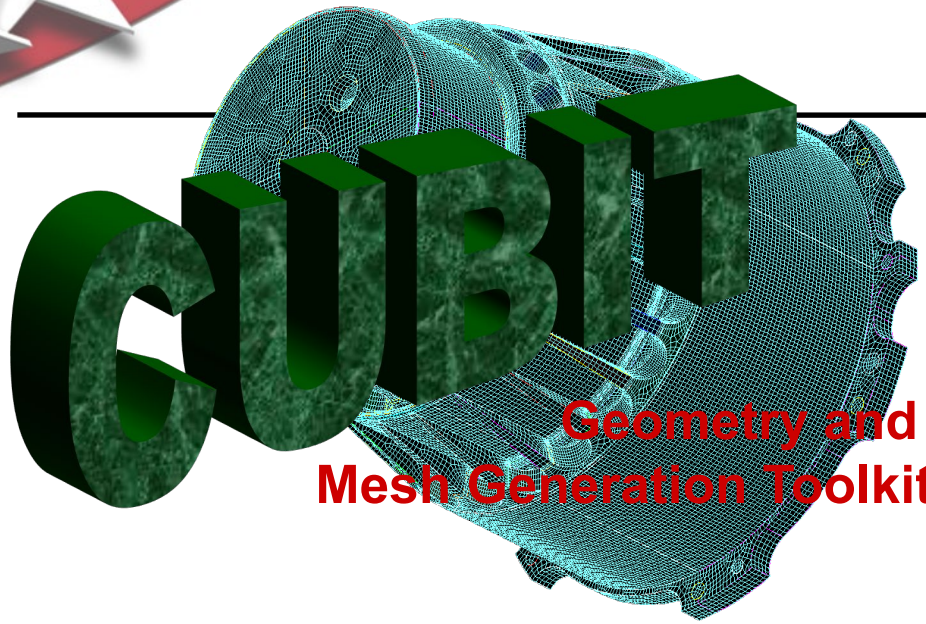


CUBIT Fast-Start Tutorial

20. Improving the Quality of Existing Hex Meshes

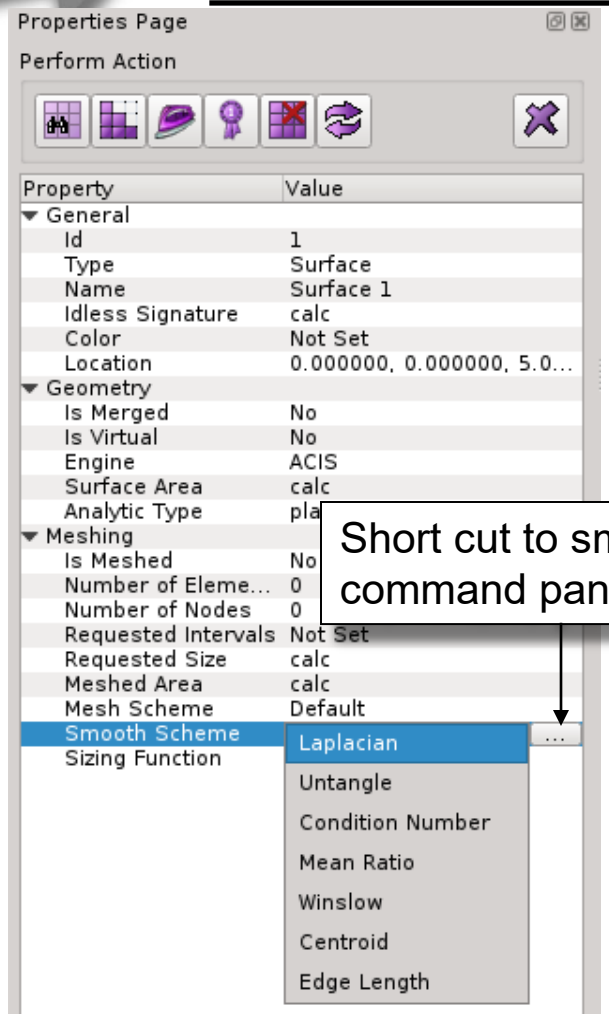
Sandia National Laboratories

Tools to Improve Quality of Existing Hex Meshes

- Smoothing
- Unite Meshed Volumes
- Mesh Surgery
- Pillowing

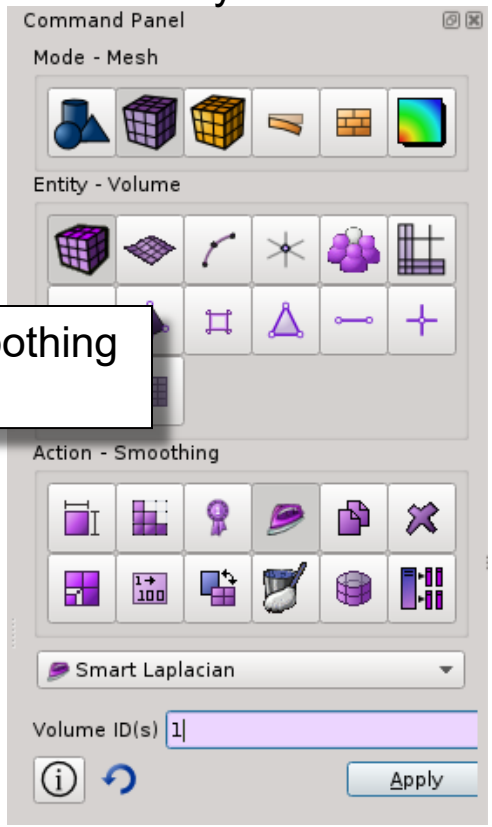
Smoothing

Smoothing adjusts node locations without changing element connectivity.



Short cut to smoothing command panel

Smooth scheme can be set from the property panel



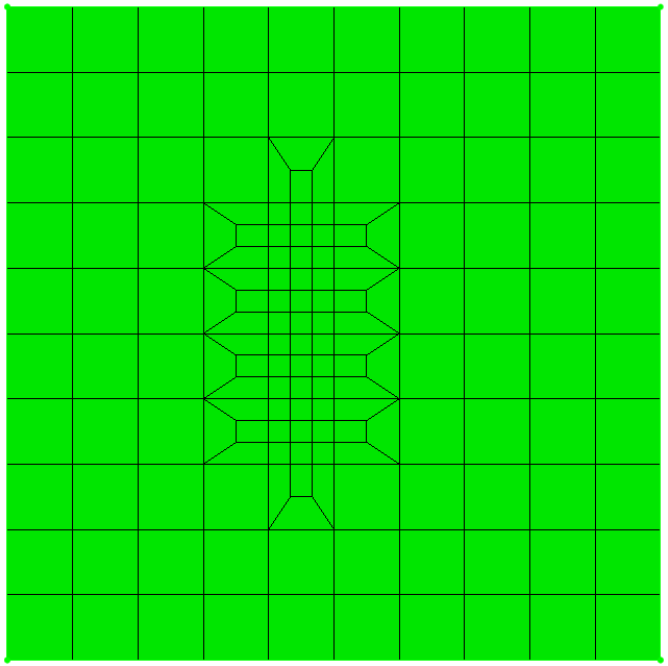
Smooth scheme can also be set from the command panel

- Many different smoothing schemes with different characteristics
- Usually iterative algorithms that attempt to improve the local mesh quality
- Smoothing schemes for surfaces and volumes
- Smoothing schemes applied as an attribute, (similar to meshing scheme)
- Surface and volume schemes are independent (unless free boundary option selected)

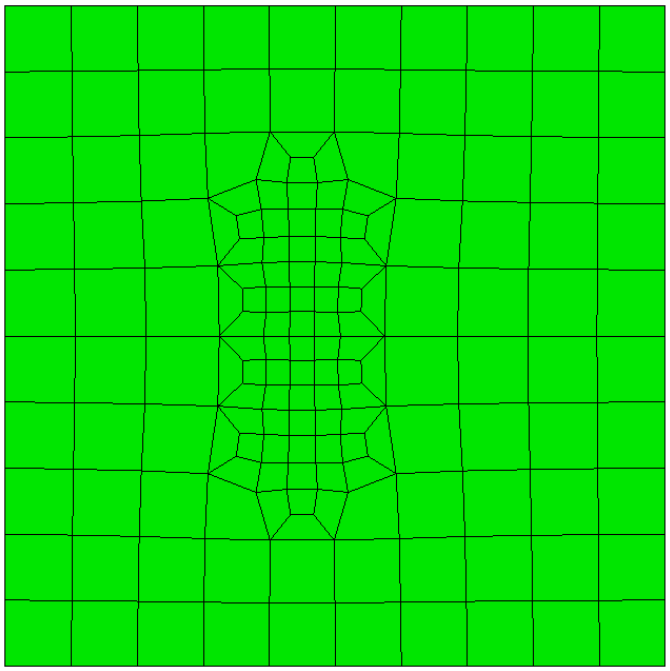
Sandia National Laboratories

Smoothing

Without Smoothing



With Smoothing



Smoothing adjusts only node locations in order to improve element quality. Some smoothing algorithms adjust nodes based on geometric criteria. Other smoothing algorithms optimize element quality metrics directly.

Smoothing

- When smoothing a surface, the nodes on the boundary curves remain fixed. If nodes on boundary need adjustment, smooth the curves first.
- Likewise, when smoothing a volume, the nodes on the boundary surfaces remain fixed. If nodes on boundary need adjustment, smooth the surfaces first.

Smoothing Process:

1. Smooth Curves
2. Smooth Surfaces
3. Smooth Volumes

Smoothing

Surface Smoothing Schemes

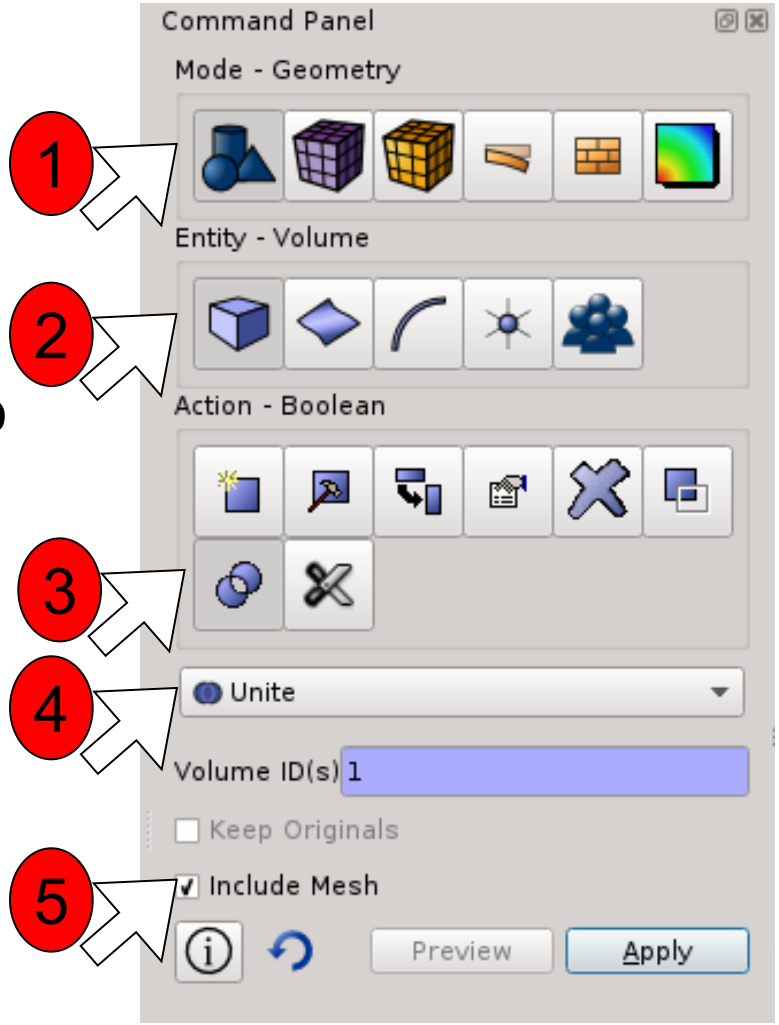
- **Equipotential**
- **Centroid Area Pull**
- **Optimize Jacobian**
- **Winslow**
  - longtime favorite for structured meshes has been extended to unstructured in CUBIT - theoretical guarantee against mesh folding
  - fast and high quality, try first
- **Laplacian, centroid area pull (smart Laplacian)**
  - fast, poor near concave features
- **Untangle**
  - remove stubborn inverted elements
- **Condition number, Mean Ratio**
  - improve stubborn low-quality elements
  - must be non-inverted to start
- **Edge Length**
  - Targets to have each edge equal length

Volume Smoothing Schemes

- **Laplacian/Smart Laplacian**
  - fast, poor quality near concave features
- **Equipotential**
  - medium fast and medium quality
- **Untangle**
  - remove stubborn inverted elements
  - Can take a long time, Control time limit: [cpu <double=10>]
- **Mean Ratio**
  - Element quality optimization based
  - Can take a long time, Control time limit: [cpu <double=10>]
- **Condition number**
  - Guarantees the same or better quality
  - improve stubborn low-quality elements
  - Can take a long time, Control time limit: [cpu <double=10>]
  - Runs untangle first if input is inverted

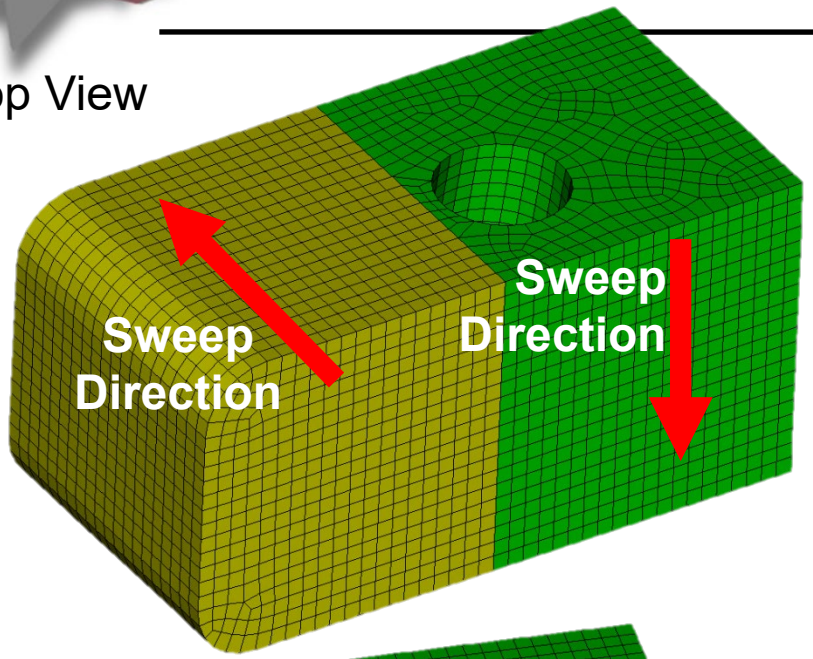
Unite Meshed Volumes

- Starting in Cubit 14.1, a new option is included on the Geometry Boolean “Unite” command which allows you to unite volumes which are already meshed.
- In previous releases, uniting volumes that were meshed resulted in deletion of the mesh.

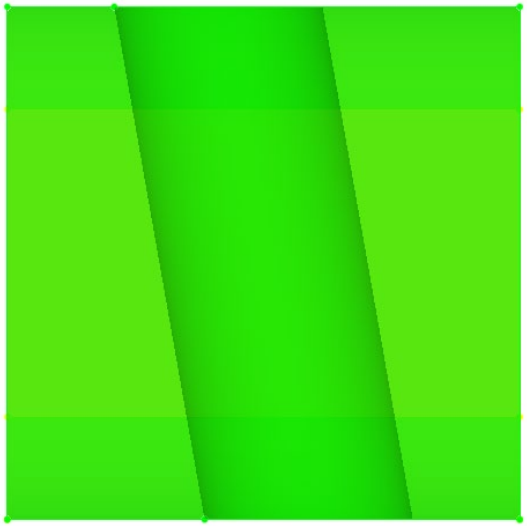


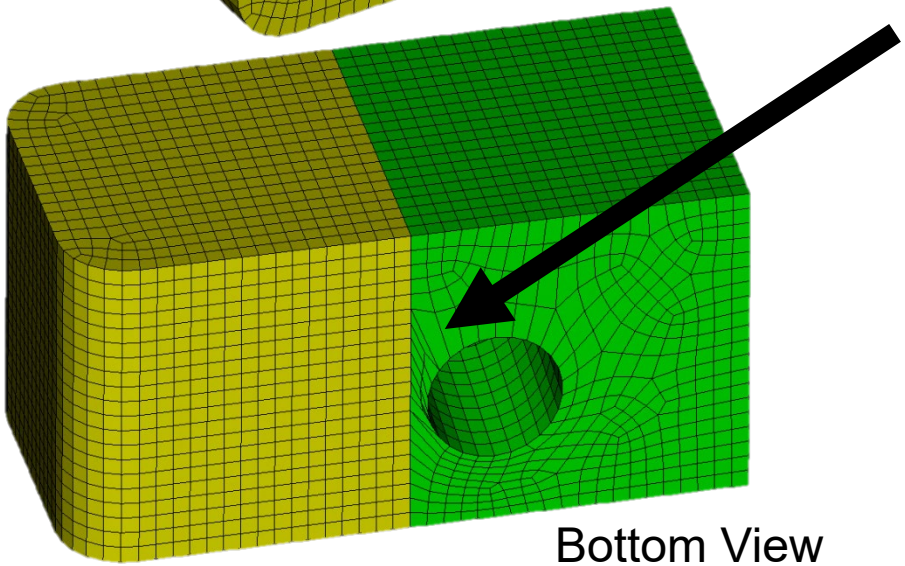
Unite Meshed Volumes

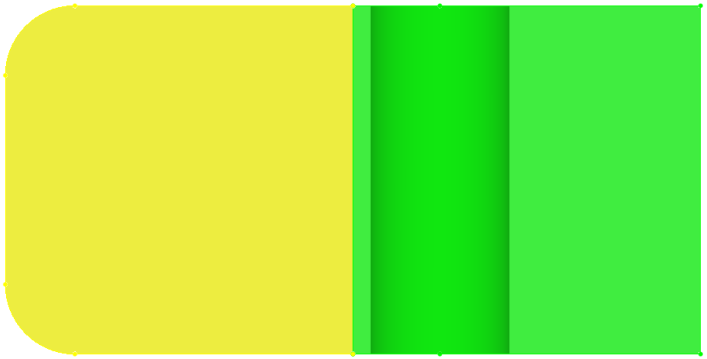
Top View



The hole is at an angle. When the source surface is swept through the volume, skew is introduced in the mesh.

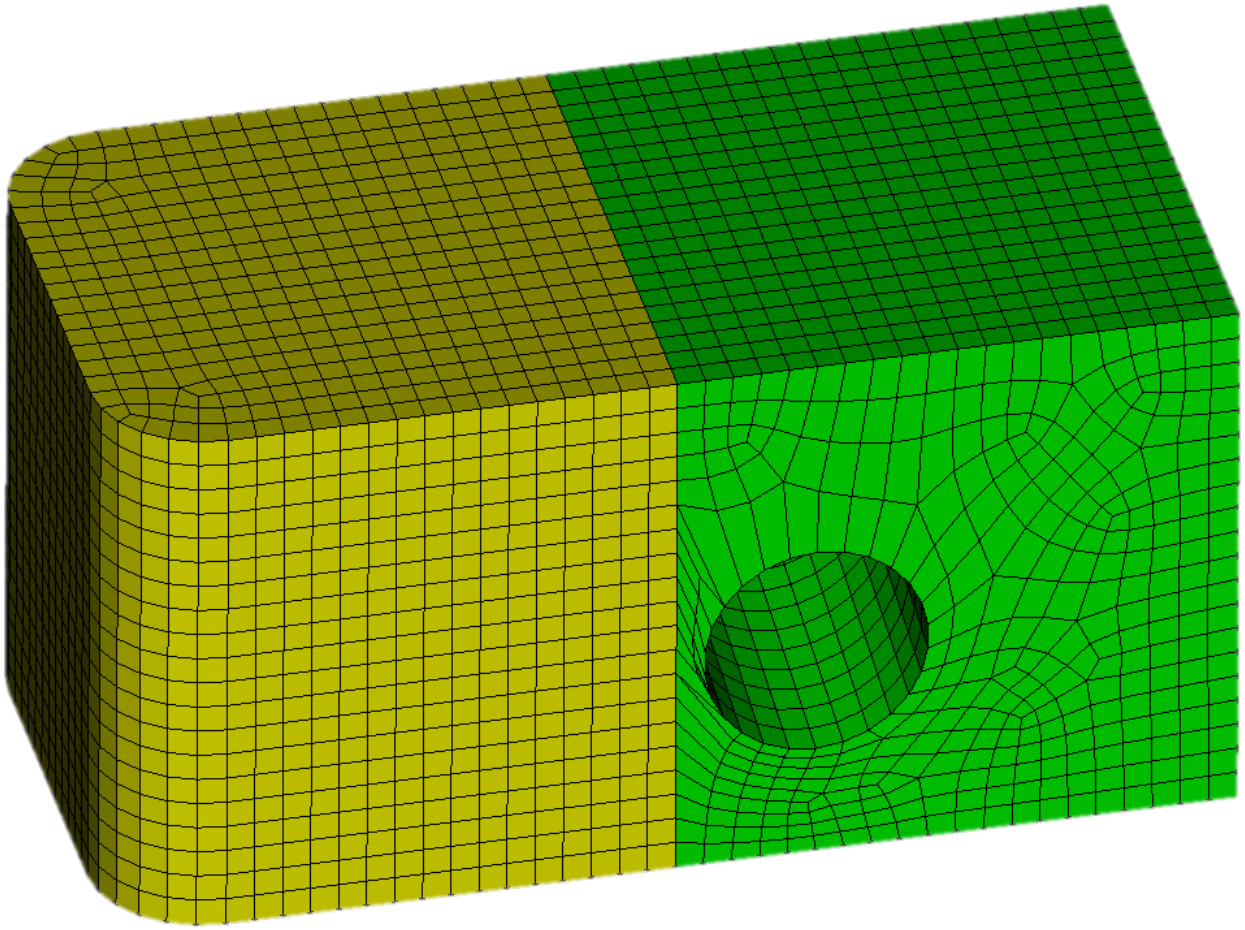






Bottom View

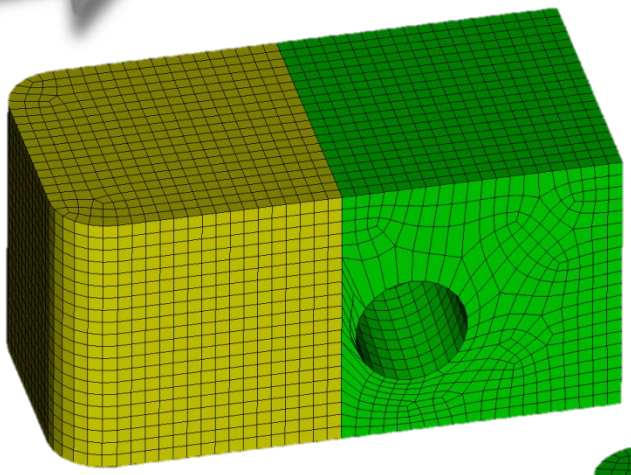
Unite Meshed Volumes



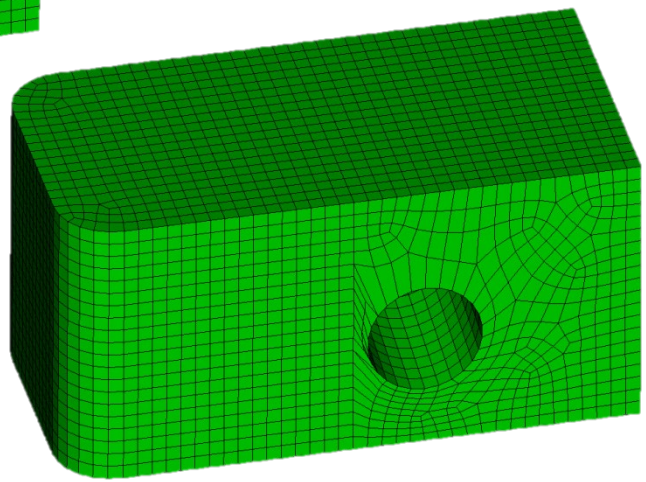
Because the hole is near the interface between the 2 volumes, smoothing alone will not improve the element quality.

However, the interface between the 2 volumes was added only to make the volume sweepable. Now that the mesh is generated, there is no need to keep the volumes separate.

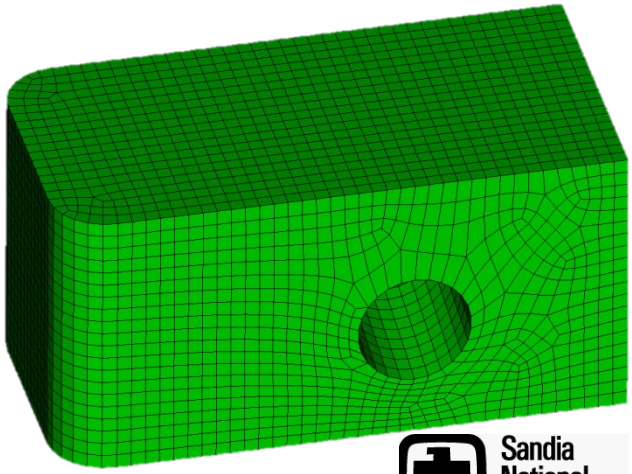
Unite Meshed Volumes



Uniting the volumes together removes the geometric constraint between the 2 volumes.

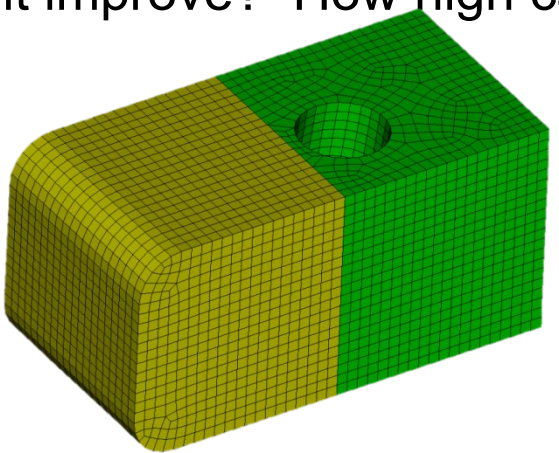


Smoothing can then optimize node locations to improve quality



Exercise 1

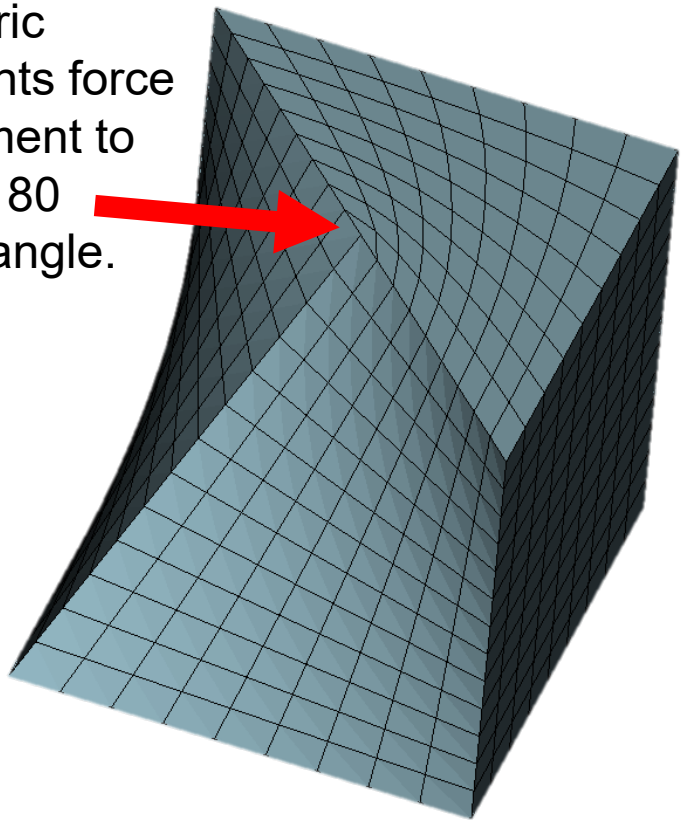
- Open UniteMeshedVolumes.cub.
- Set a mesh size of 0.5
- Mesh both volumes
- Examine the quality of the mesh. Why is the quality so poor?
- Unite the 2 volumes together. Make sure to use “include_mesh”.
- Experiment with the different smoothing schemes to improve the quality. Remember to first smooth the surfaces, and then the volume mesh. Keep running the smoother again and again until the element quality stops improving.
- Re-examine element quality. Did it improve? How high can you get the element quality?



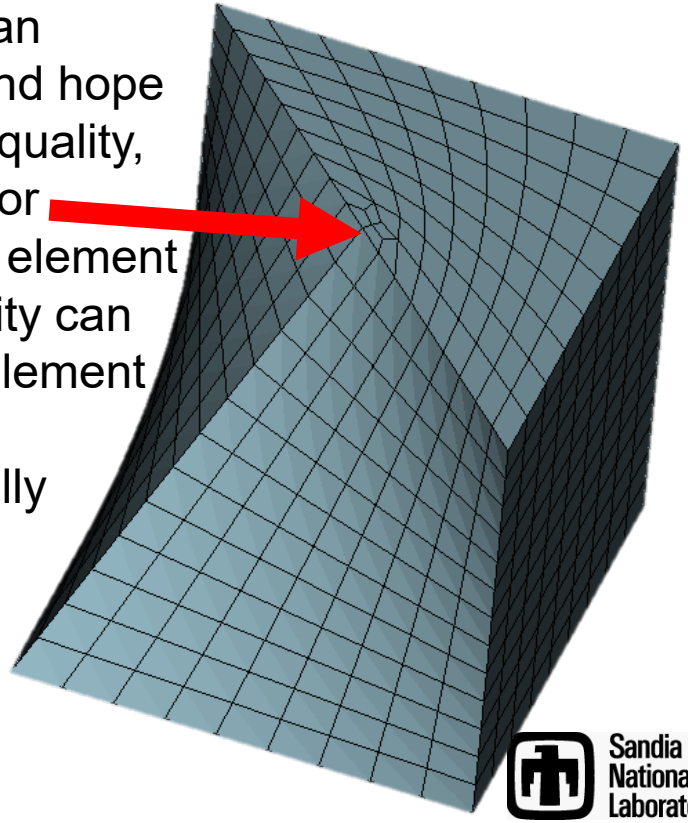
Mesh Surgery

- Sometimes adjusting node locations alone (i.e. smoothing) is not enough to fix poor element quality. Sometimes we need to change the element connectivity also. For example:

Geometric constraints force this element to have a 180 degree angle.

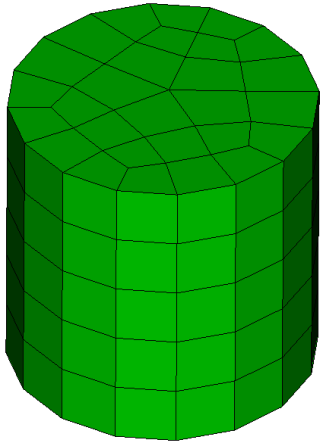


Rather than remesh and hope for better quality, a few minor tweaks to element connectivity can improve element quality dramatically

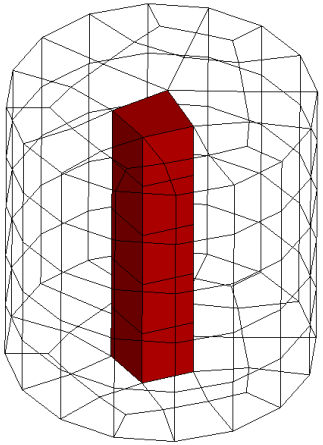


Mesh Surgery

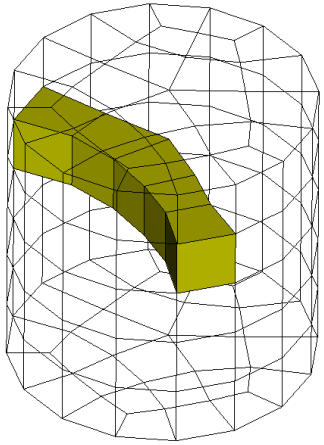
- Mesh Surgery can be used to import legacy meshes or meshes from other meshing packages to improve their quality.
- Mesh Surgery is based on performing “Column operations”
- A column is a stack of hexahedra within the mesh.
- You can draw a column of hexes with the following command: ***draw column face <id>,*** where the id refers to a quad face which is at one end of the column.



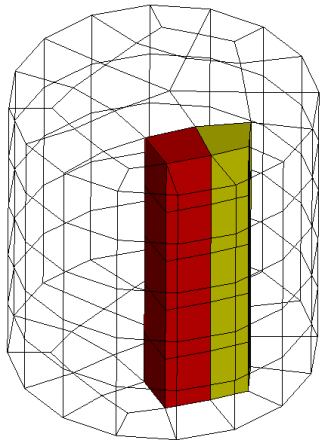
An example hex mesh



A column running along the sweep direction.



A column running perpendicular to the sweep direction



Two adjacent columns

Exercise 2 – Drawing Hex Columns

- Create a cylinder and mesh it with hexes
- Pick different faces on the boundary of the mesh and draw the corresponding columns.
- Use the Cubit command: ***draw column face <id>***
- After drawing a column, type ***"draw edge all add"*** so you can see the column with respect to the rest of the model.
- After visualizing one column, reset the display by hitting ***F5*** so you can pick and draw a different column.

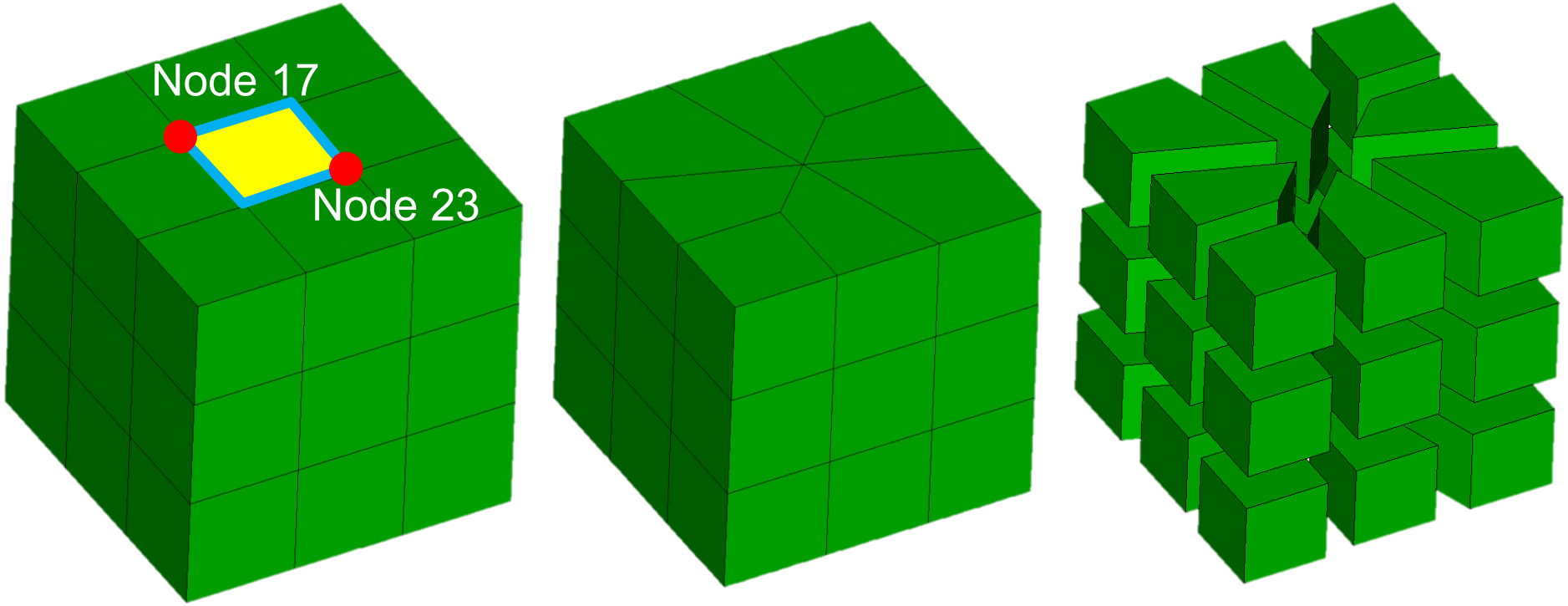
Mesh Surgery

- There are 3 basic mesh surgery operations:
  - Column Collapse
  - Column Split
  - Column Swap

Mesh Surgery – Column Collapse

CUBIT Command syntax:

Column collapse node <node_id> <opposite_node_id>



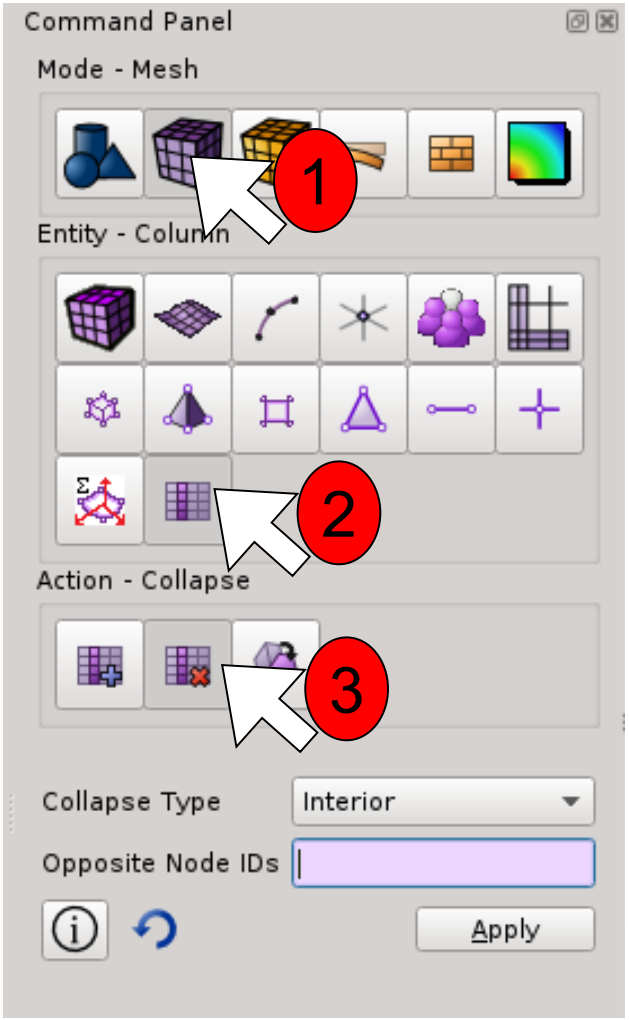
For Example: ***Column collapse node 17 23***

Mesh Surgery – Column Collapse - GUI

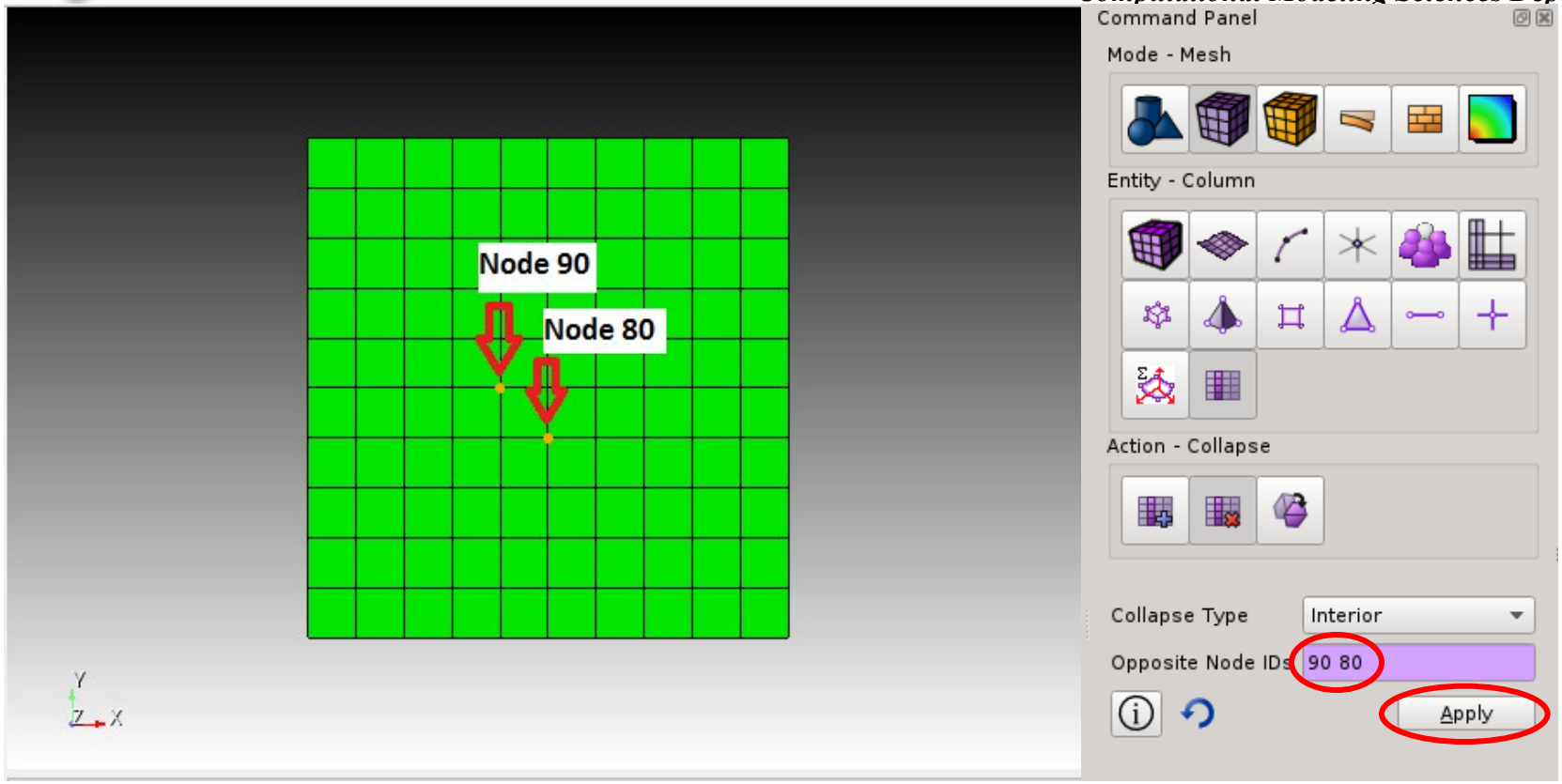
Computational Modeling Sciences Department

In the Command Panel Select:

1. Mode - Mesh
2. Entity – Column
3. Action - Collapse



Mesh Surgery – Column Collapse - GUI

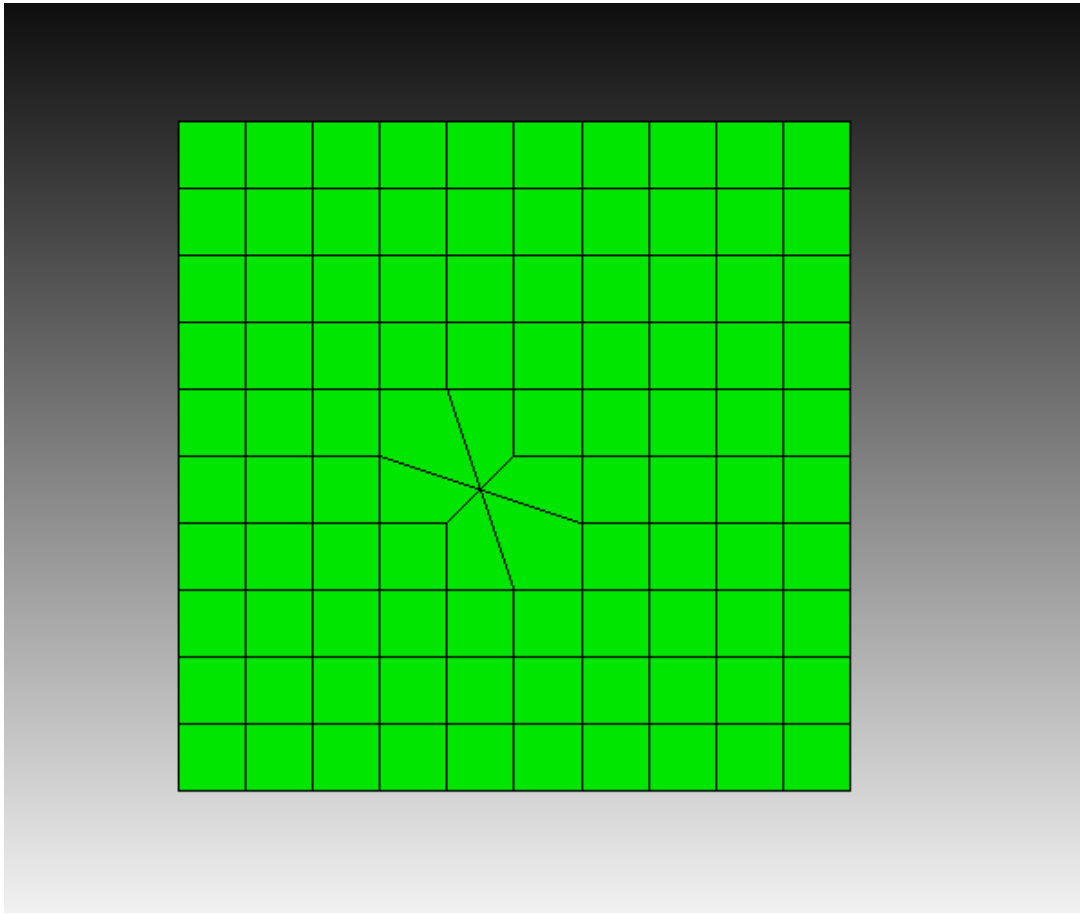


1. Click Cursor in the Opposite Node Box
2. Select the nodes you wish to collapse
3. With two opposite nodes in the Opposite Node ids Box click Apply

Mesh Surgery – Column Collapse - GUI

Computational Modeling Sciences Department

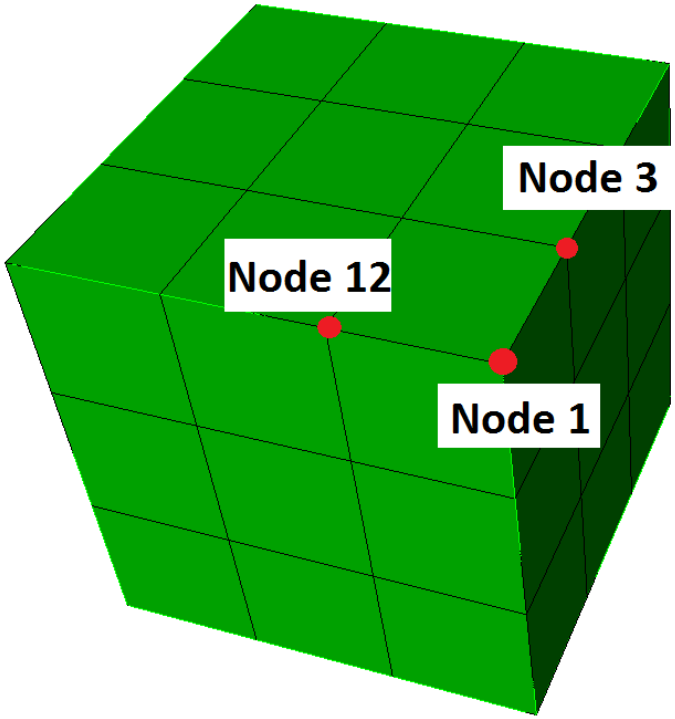
Column Collapse Result

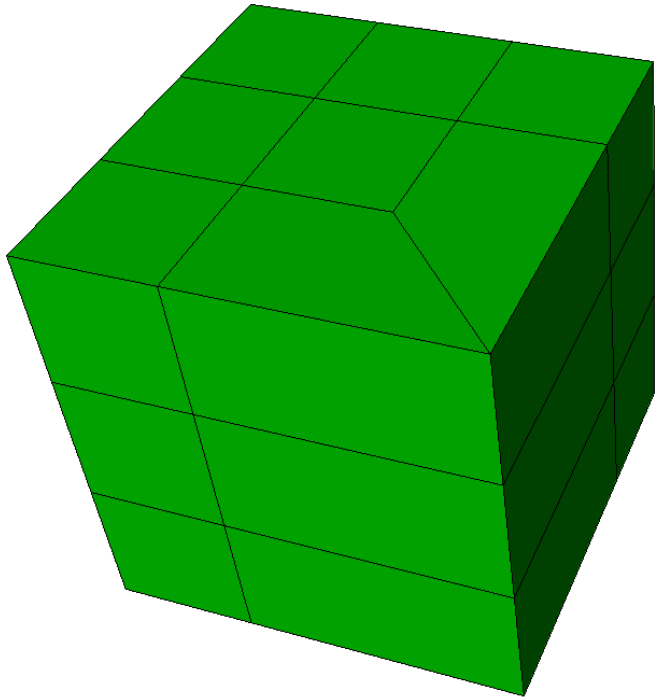


Mesh Surgery – Column Collapse Boundary

CUBIT Command syntax:

Column collapse boundary node <node id> <corner node id> <node_id>



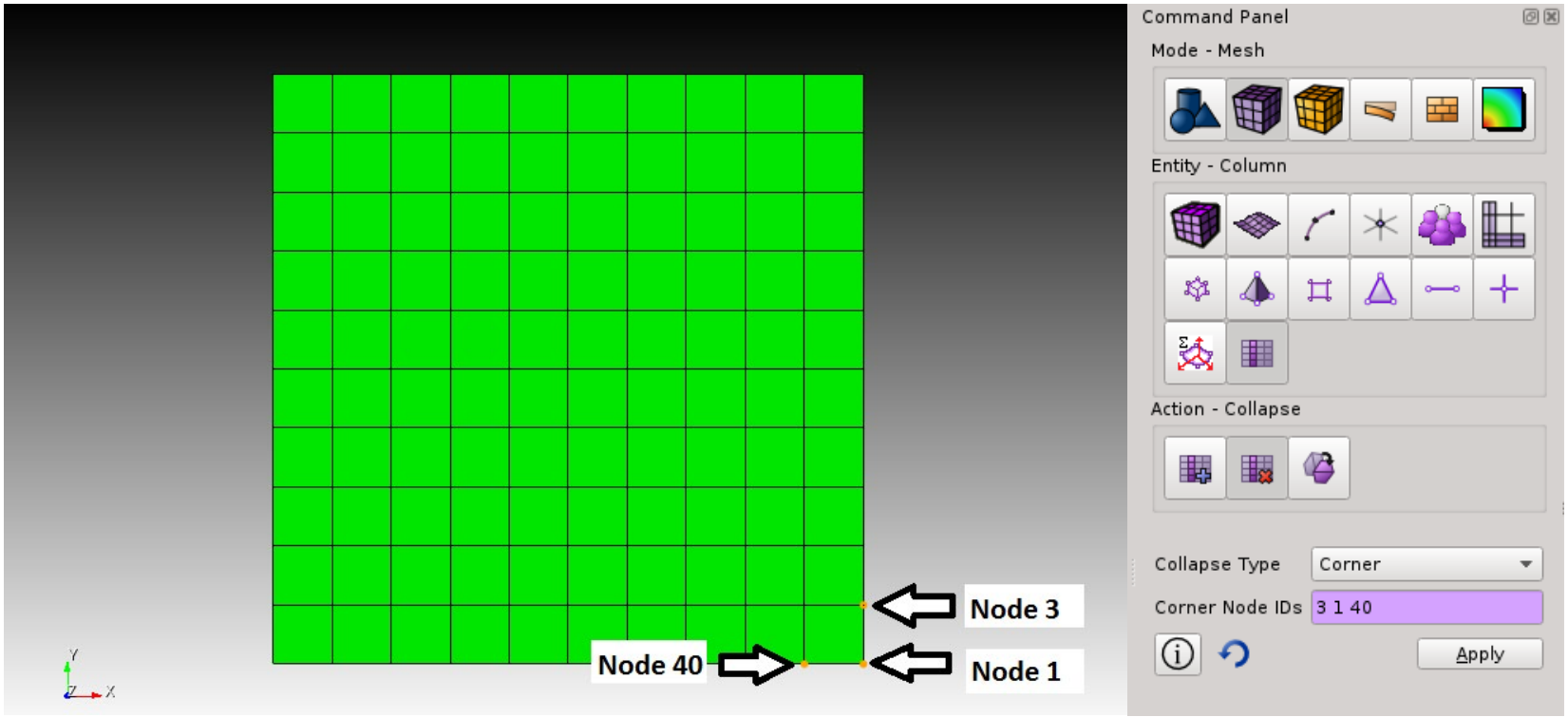


Collapses adjacent boundary nodes onto corner node

For Example: ***column collapse boundary node 3 1 12***

Mesh Surgery – Column Collapse Corner - GUI

Computational Modeling Sciences Department

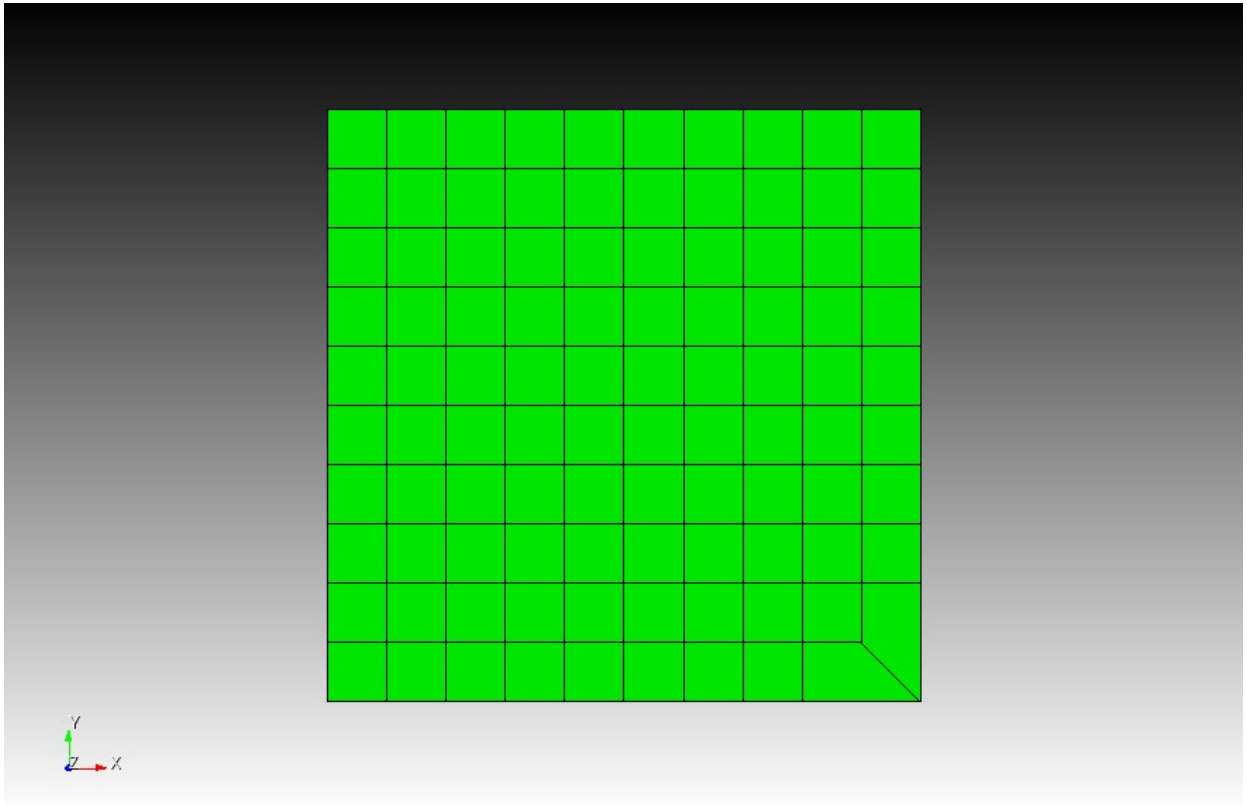


To collapse at a corner, select boundary node, corner node, boundary node, in that order, where the two boundary nodes must be opposite one another. Hit the apply button.

Mesh Surgery – Column Collapse Corner - GUI

Computational Modeling Sciences Department

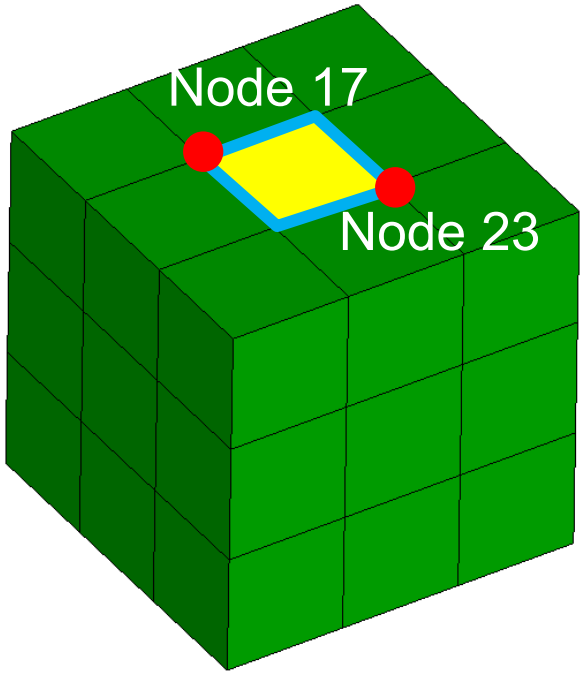
Collapse Corner Result

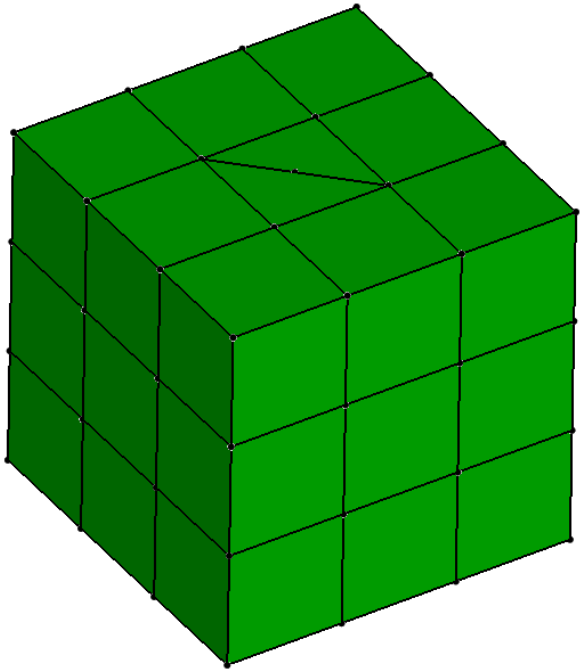


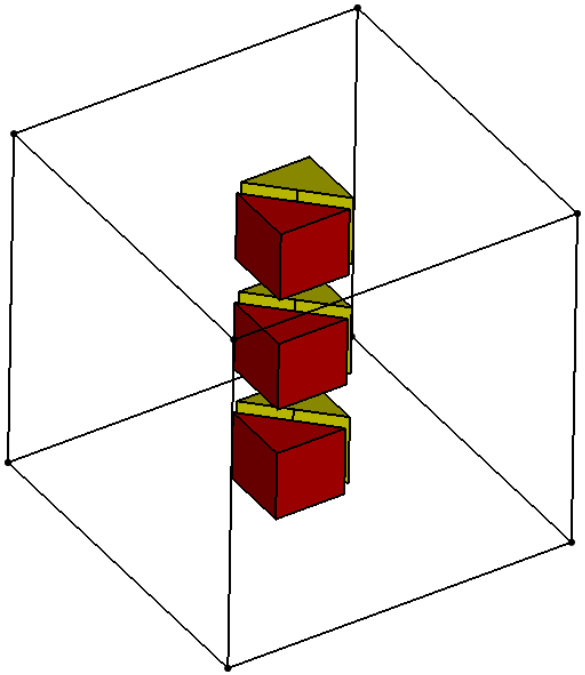
Mesh Surgery – Column Split

CUBIT Command syntax:

Column split node <node_id> <opposite_node_id>





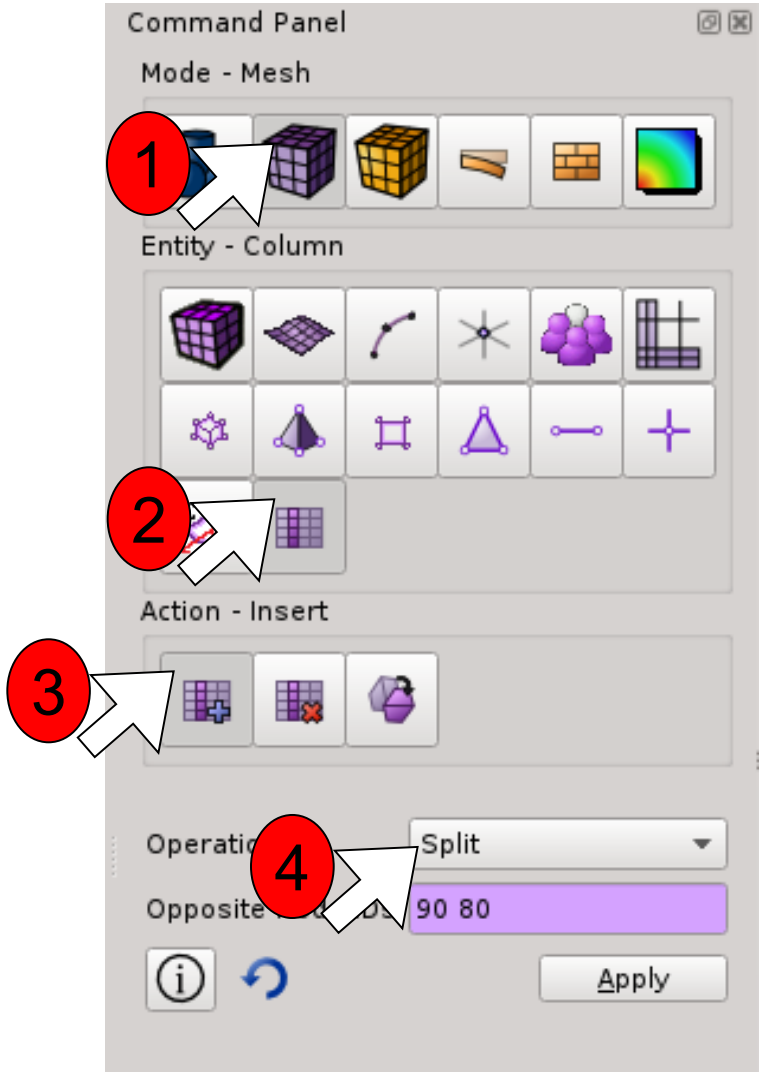


For Example: ***Column split node 17 23***

Creates 2 columns of very poorly shaped flat hexes. Always an intermediate step, followed by something else.

Mesh Surgery – Column Split - GUI

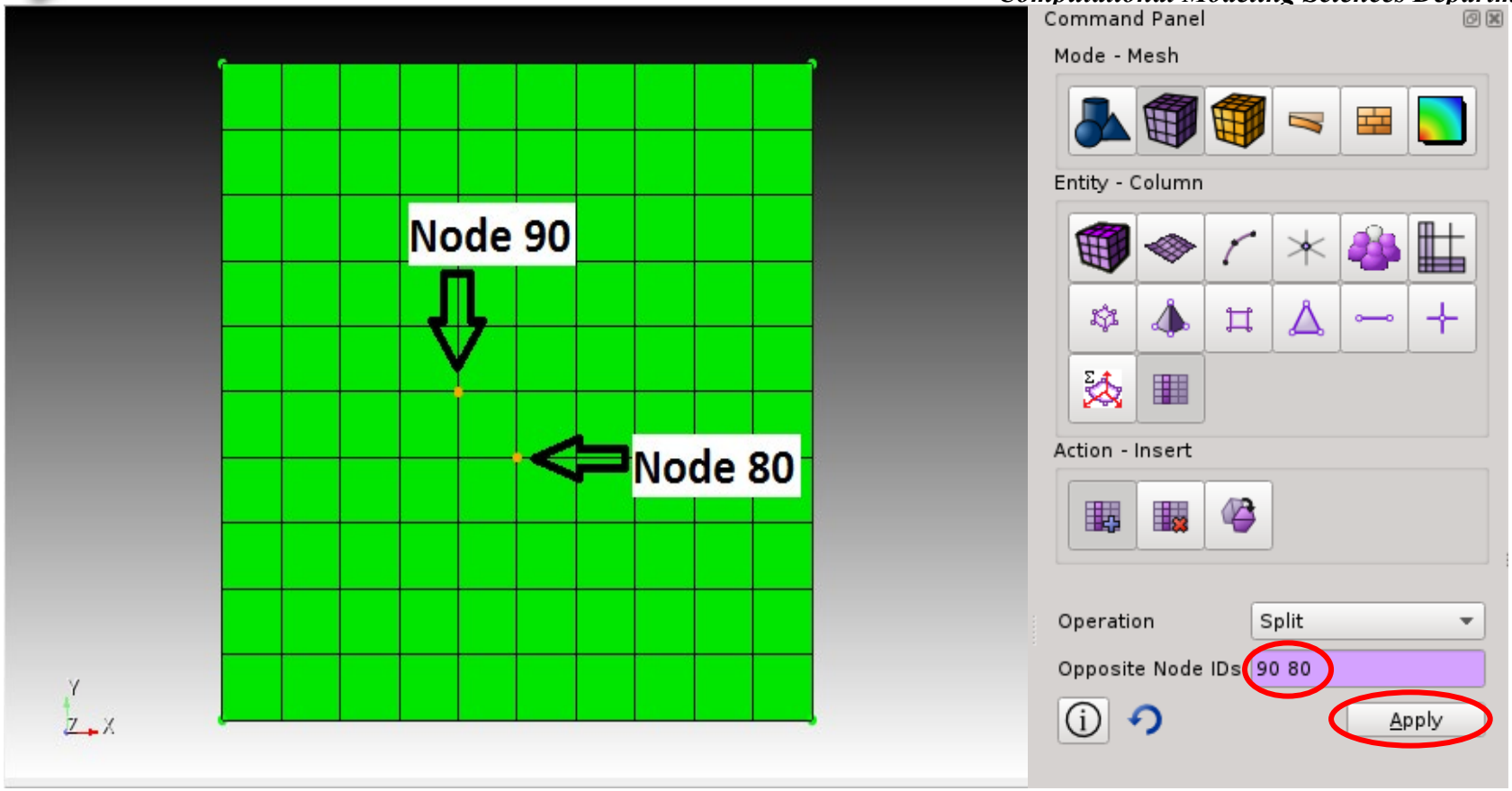
Computational Modeling Sciences Department



In the Command Panel select:

1. Mode – Mesh
2. Entity – Column
3. Action – Insert
4. Operation – Split

Mesh Surgery – Column Split - GUI

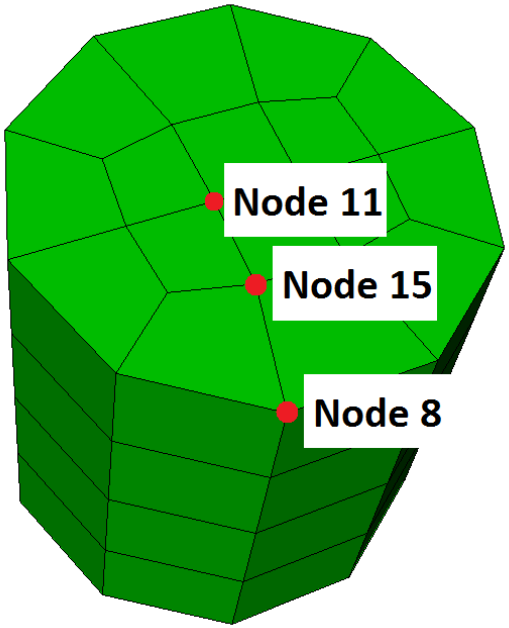


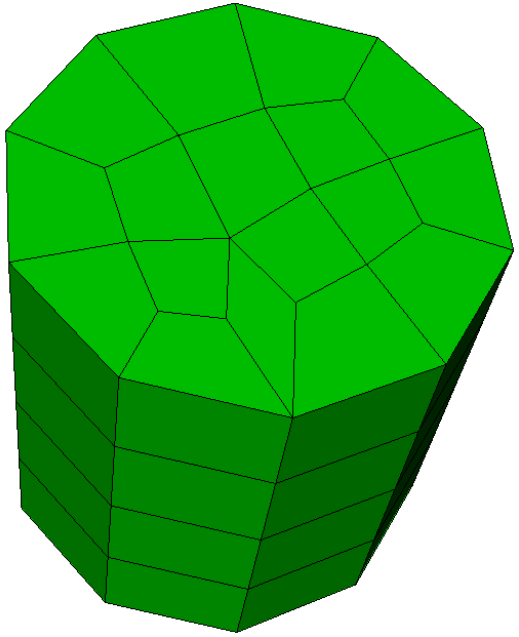
To Use the Split command:
-click cursor in Opposite Node ID box
-Selection two opposite nodes on the meshed volume.
-Hit the apply button.

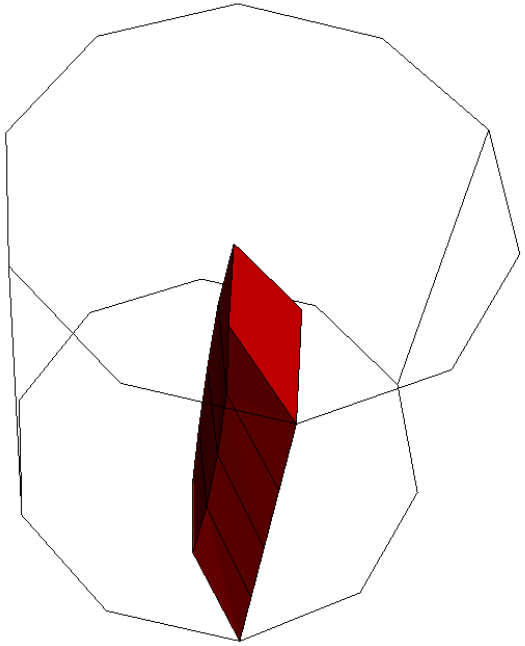
Mesh Surgery – Column Open

CUBIT Command syntax:

Column open node <center node id> <orientation node ids>



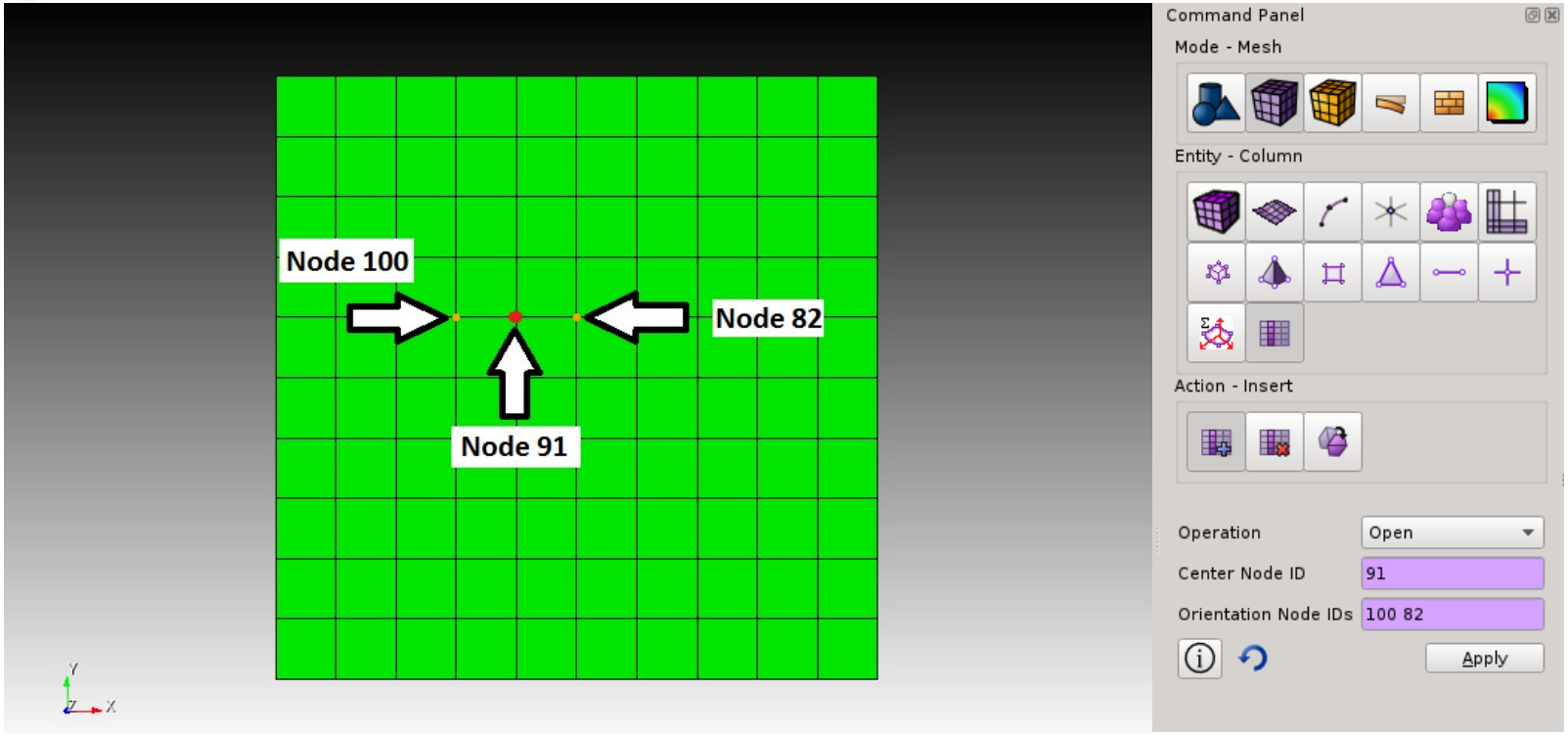




For Example: ***Column open node 11 15 8***

Center node must be 4-valent and orientation nodes must be opposite one another about center node.

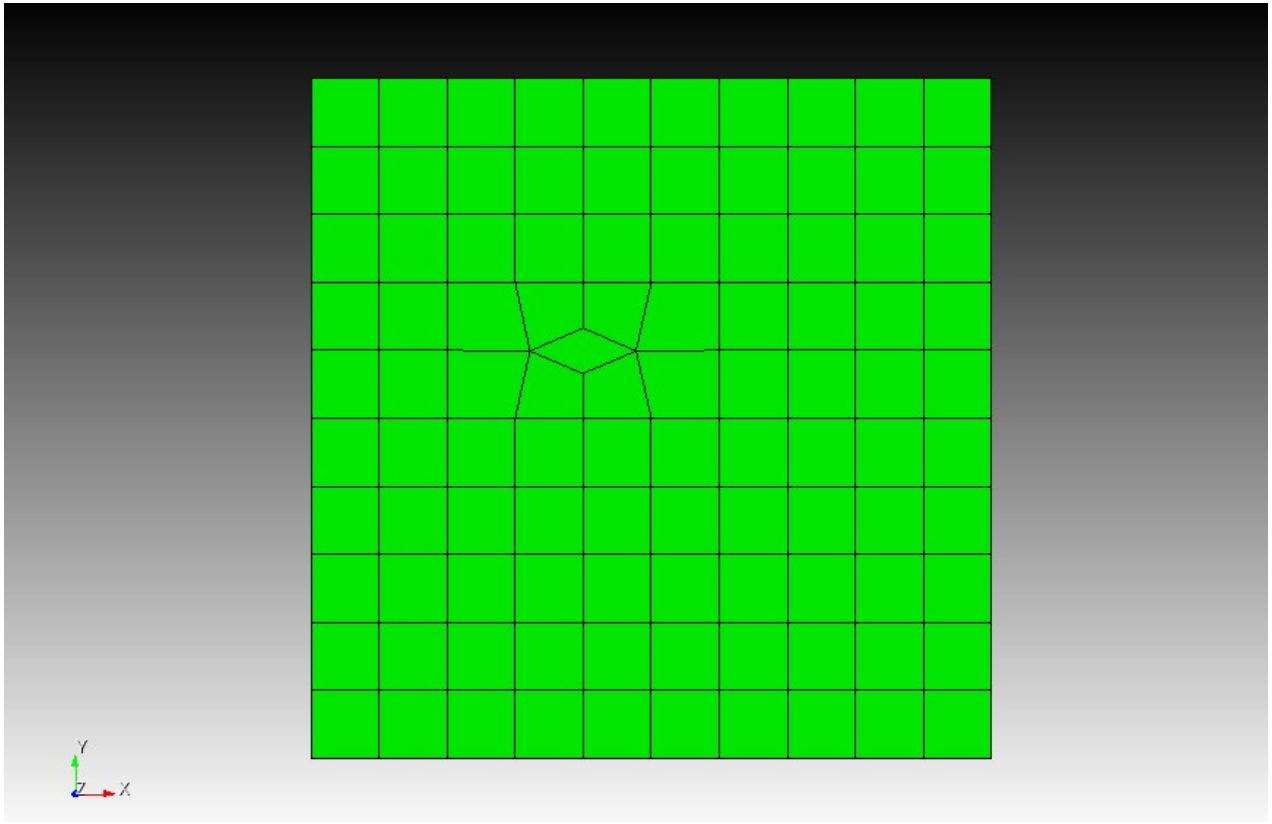
Mesh Surgery – Column Open - GUI



To perform a column open operation, specify 'open' as the operation, then select a center node, then two orientation nodes, which must be opposite one another about the center node. Hit the apply button.

Mesh Surgery – Column Open - GUI

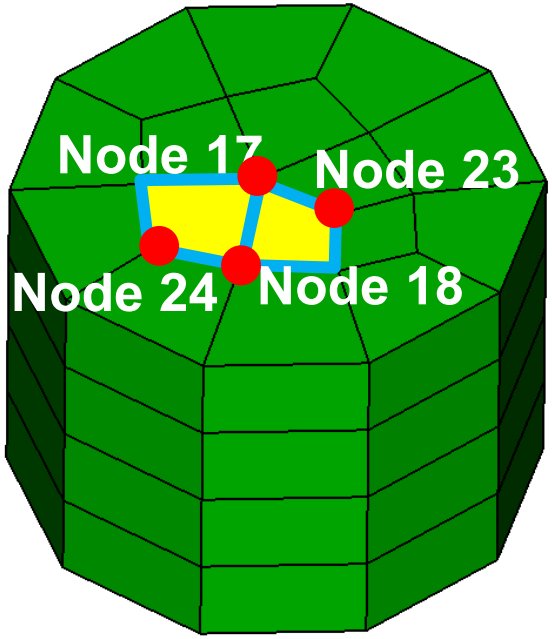
Column Open Result

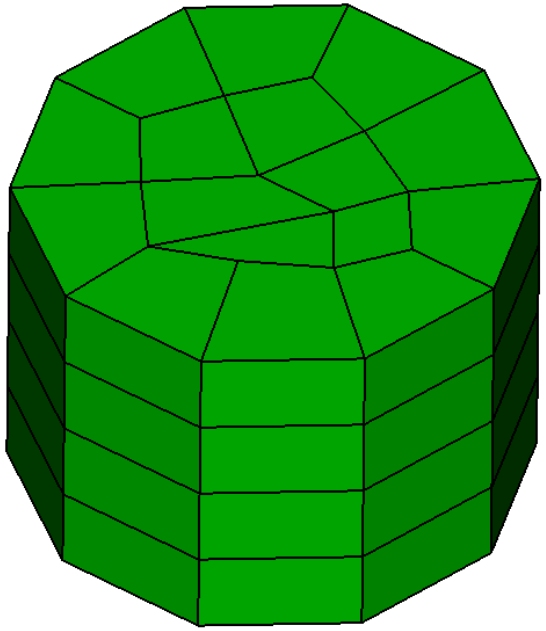


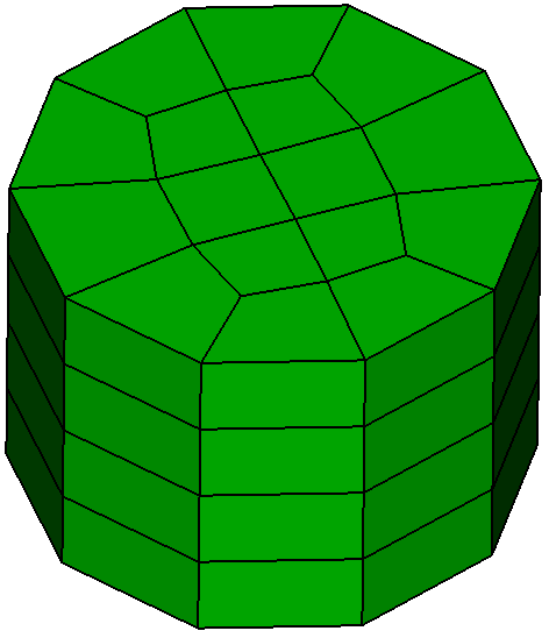
Mesh Surgery – Column Swap

CUBIT Command syntax:

Column swap node <node_id1> <node_id2> <node_id3> <node_id4>







Smoothing is then performed to smooth out topology

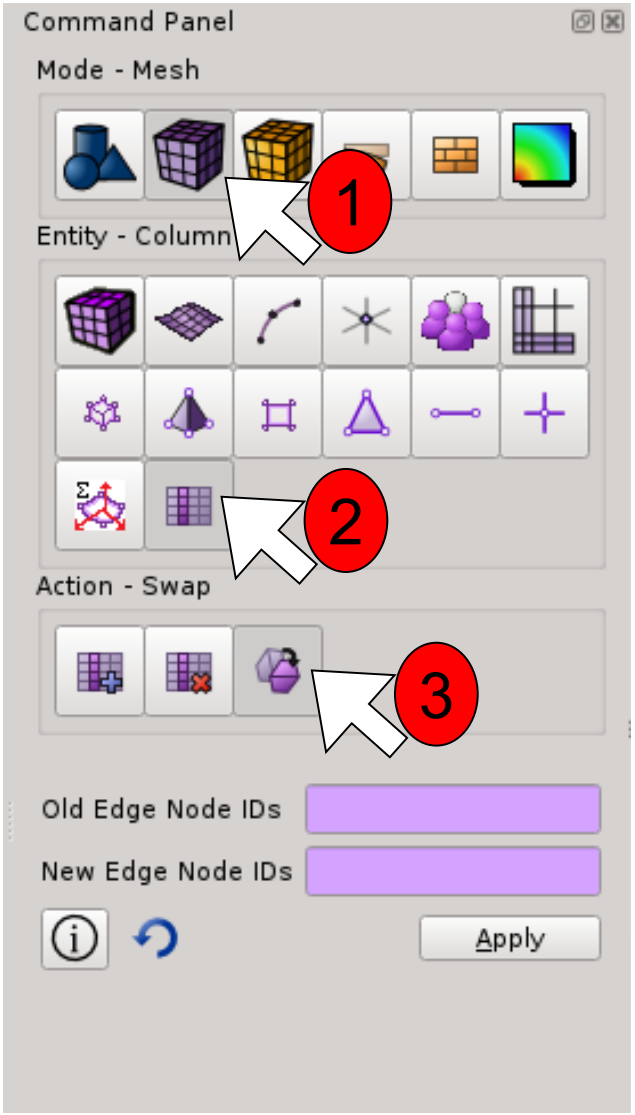
For Example: ***Column swap node 17 18 23 24***

Column swapping is performed on 2 adjacent columns, which must be parallel along their entire path.

Mesh Surgery – Column Swap - GUI

In the Command Panel Select:

1. Mode – Mesh
2. Entity – Column
3. Action – Swap

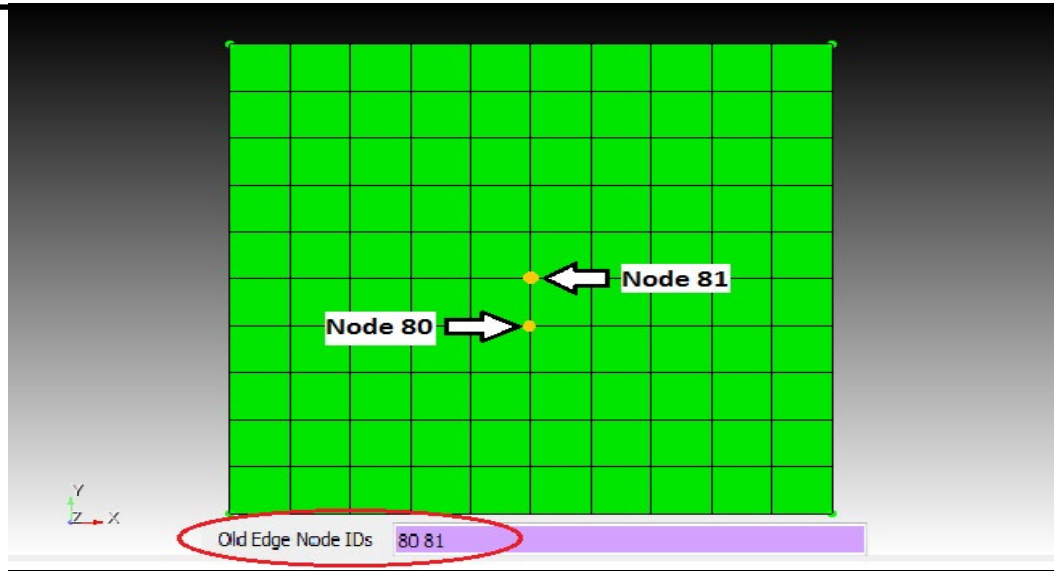


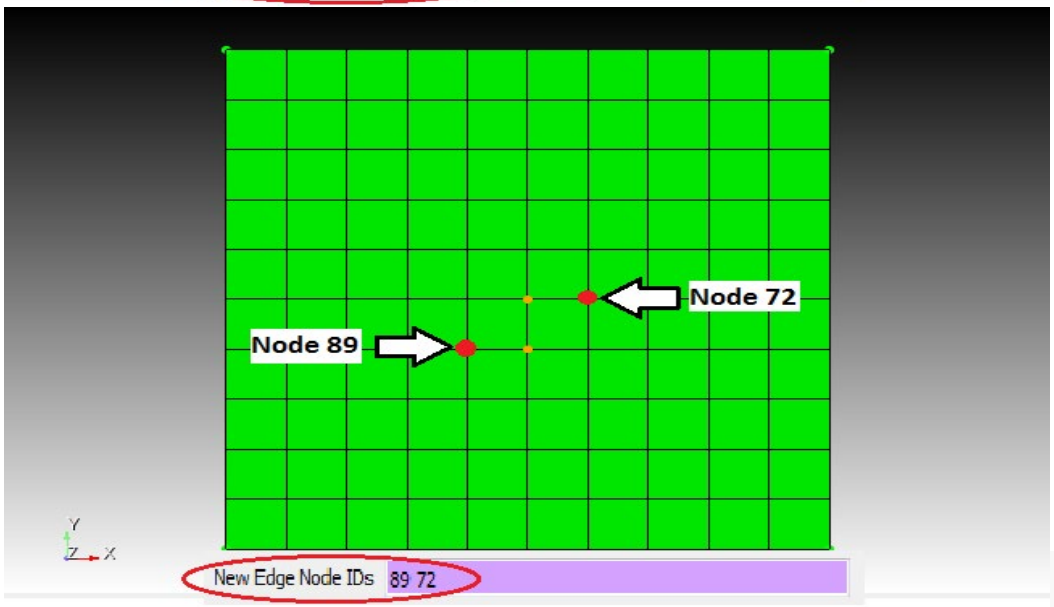
Mesh Surgery – Column Swap - GUI

In the Command Panel move the cursor into the Old Edge Node box.
Then select two end nodes of the old edge.

Next select the New Edge Node box. In the picture on the right the yellow dots represent the nodes chosen for old edge nodes. Select the two nodes that you want to connect with the new edge.

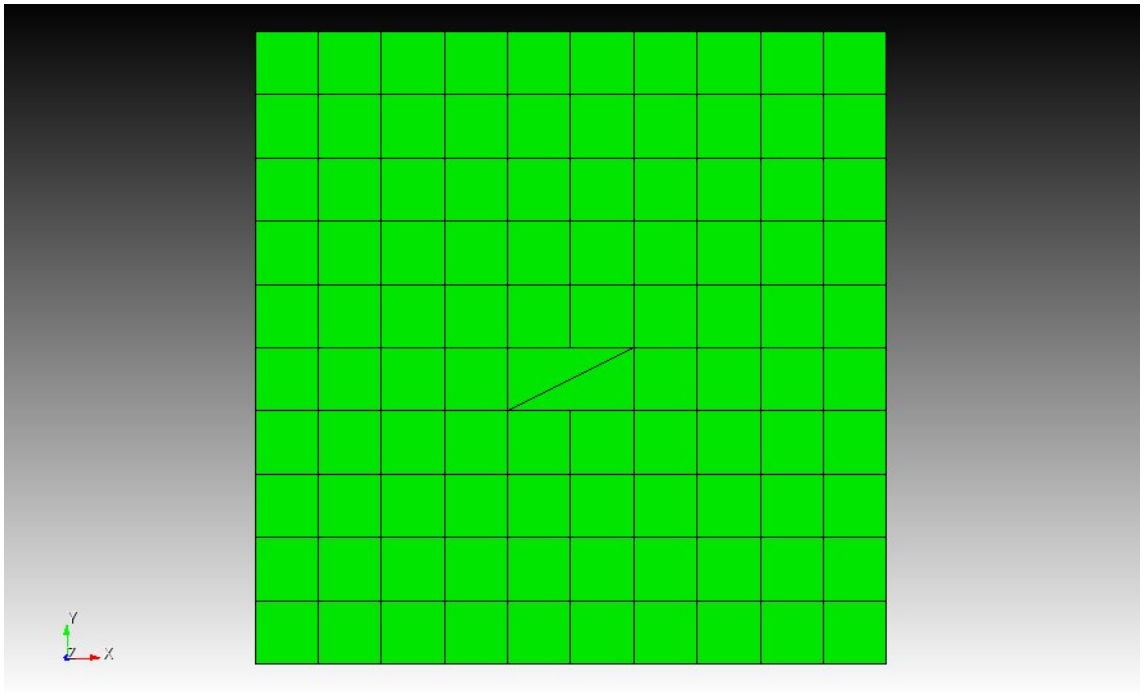
When you have two correct nodes in both the new and old edge boxes hit apply.



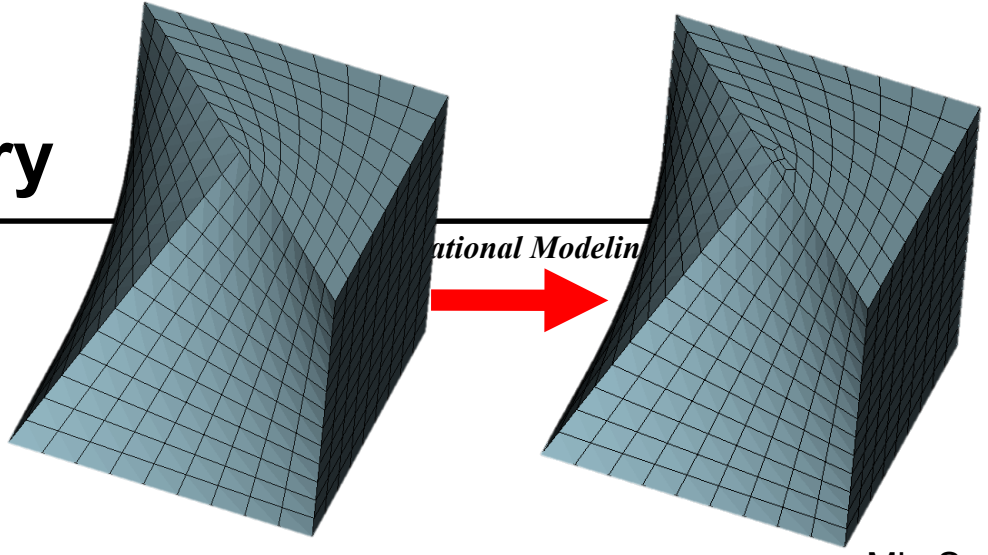


Mesh Surgery – Column Swap - GUI

Column Swap Result

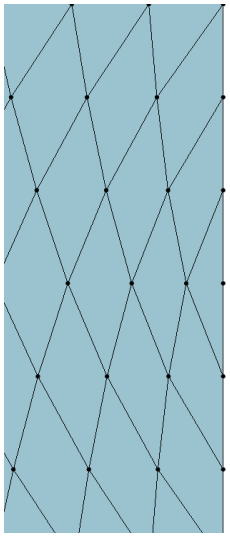


Mesh Surgery

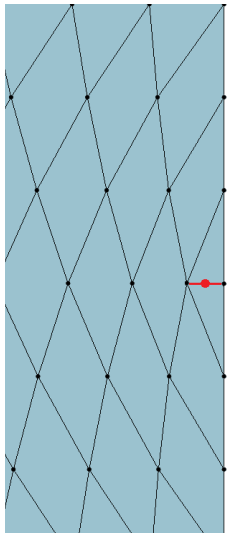


- Several Column operations are normally done in sequence to effect a change.

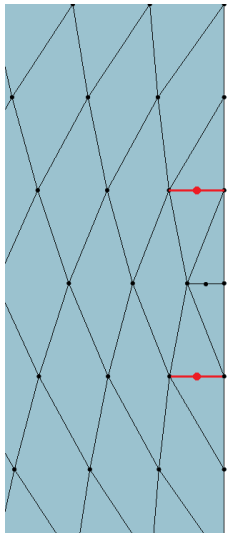
Min Scaled Jacobian: 0.0



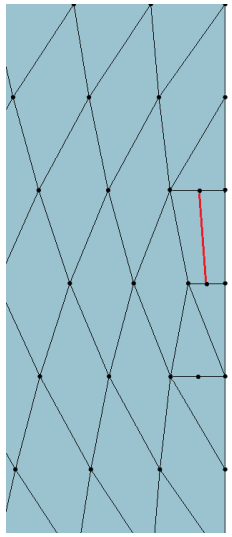
Initial Mesh



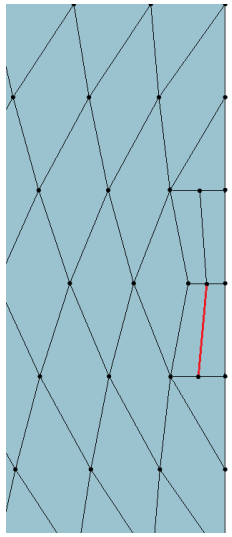
Step 1: split column



Step 2: Split two more columns

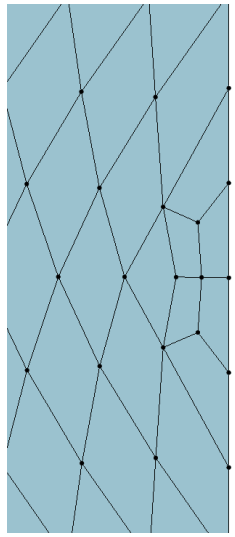


Step 3: Swap between two columns



Step 4: Another swap between two columns

Min Scaled Jacobian: 0.47



Step 5: Smooth to improve element quality.

Sandia National Laboratories

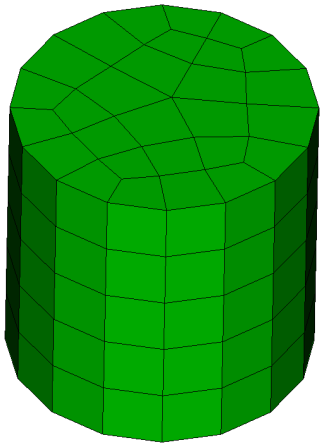
Exercise 3 – Mesh Surgery

- Create a cylinder and mesh it with hexes
- Practice using the ***column collapse*** operation on a few columns:
  - *Column collapse node <node_id> <opposite_node_id>*
- Practice using the ***column split*** operation on a few columns:
  - *Column split node <node_id> <opposite_node_id>*
- Practice using the **column swap** operation on a few pairs of adjacent columns:
  - *Column swap node <node_id1> <node_id2> <node_id3> <node_id4>*
- Try these operations on columns that are parallel to sweep direction as well as perpendicular to sweep direction.
- Remember to smooth the mesh after performing a column operation.
- Do column operations always improve element quality?

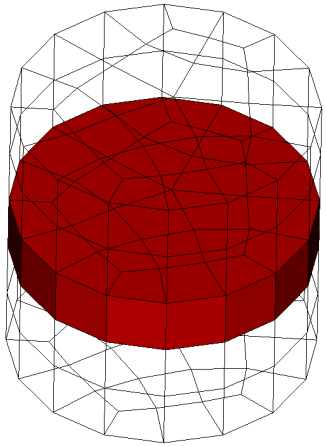
Hex Mesh Sheets

- A hex mesh sheet is a continuous layer of hexes in a mesh.
- You can draw a sheet of hexes with the following command: ***draw sheet edge <id> mesh,*** where the id refers to an edge which is in the sheet.

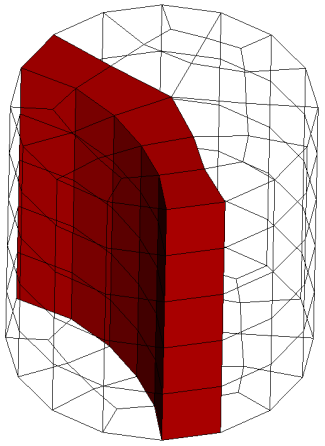
> **Note**: ***draw sheet*** is a developer command. Use the follow command before using: ***set dev on***



An example hex mesh



A sheet perpendicular to the sweep direction



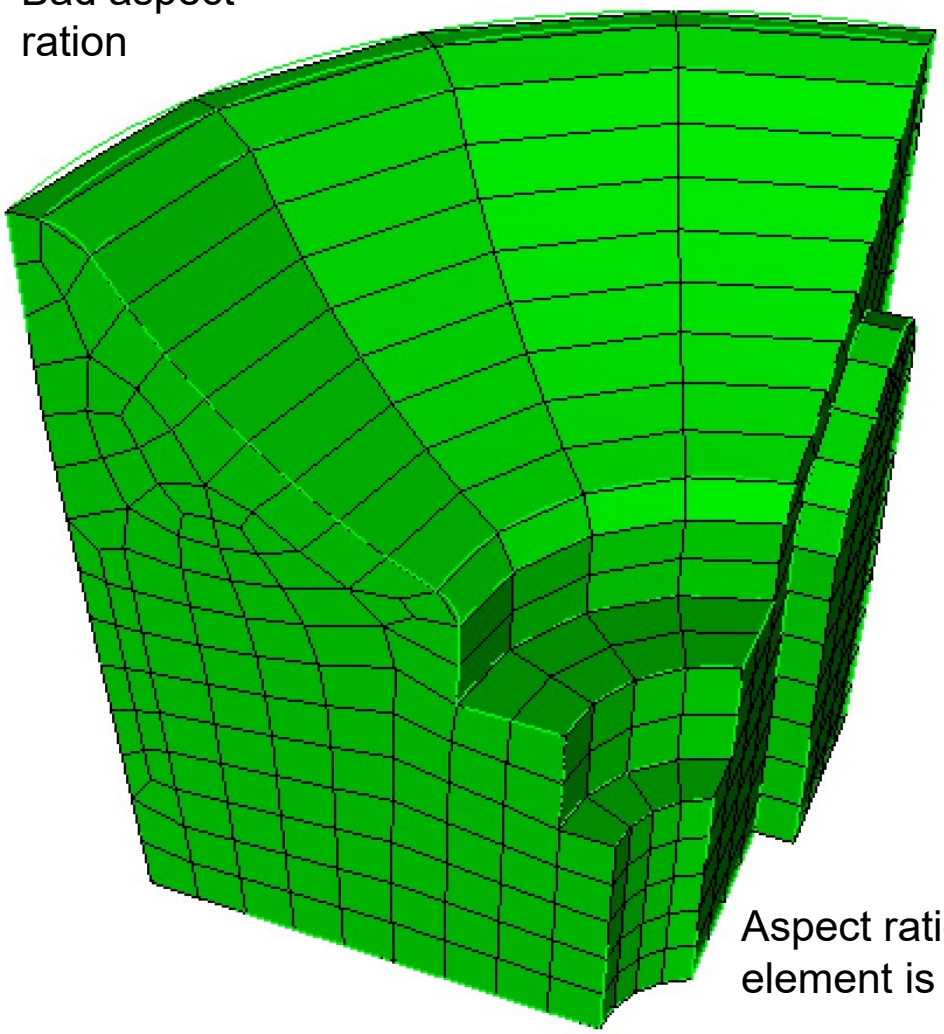
A sheet parallel to sweep direction

Exercise 4 – Drawing Sheets

- Create a cylinder and mesh it with hexes
- Pick different edges on the boundary of the mesh and draw the corresponding sheets.
- Use the Cubit command: ***draw sheet edge <id> mesh***
- After drawing a sheet, type ***"draw edge all add"*** so you can see the sheet with respect to the rest of the model.
- After visualizing one sheet, reset the display by hitting ***F5*** so you can pick and draw a different sheet.

Inserting sheets

Bad aspect ration

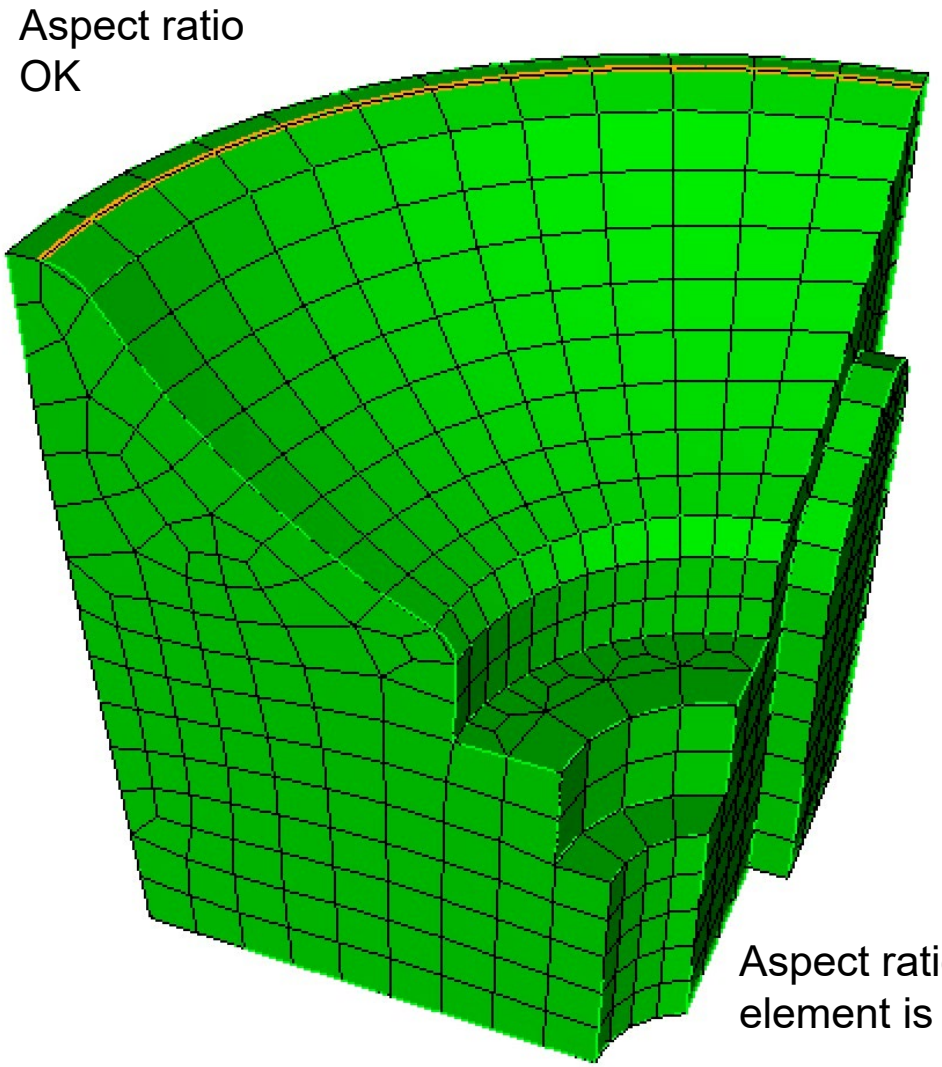


Aspect ratio of element is OK

Rotational pave-sweep

- Insert sheets to refine only the bad aspect ratio elements without refining the good

Inserting sheets



Rotational pave-sweep

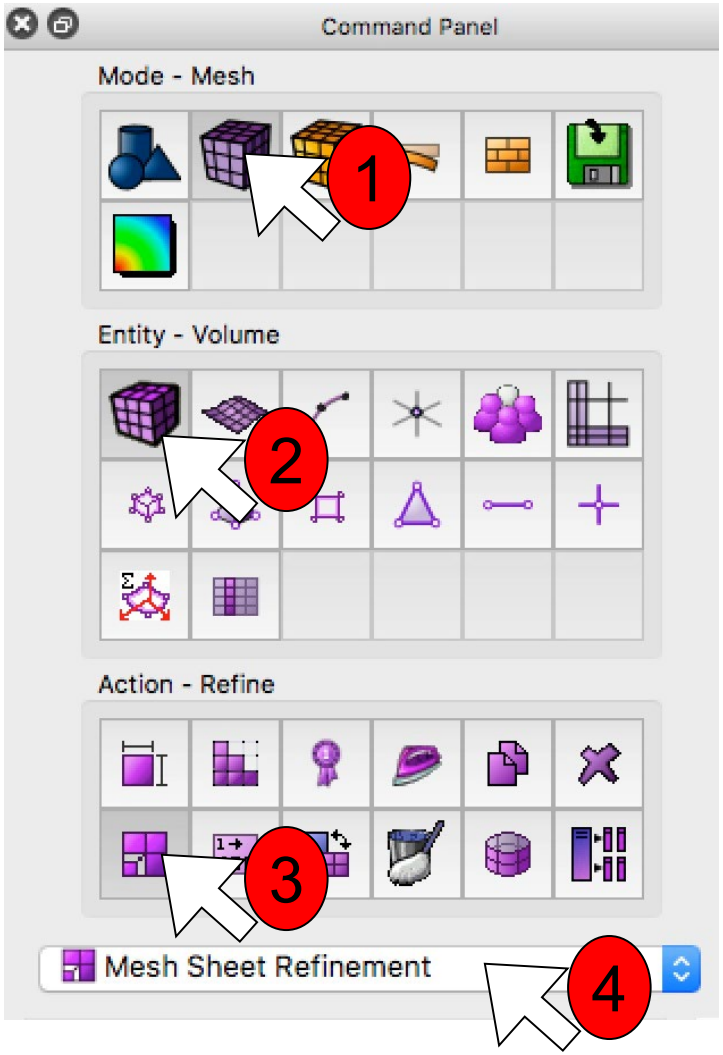
- Insert sheets to refine only the bad aspect ratio elements without refining the good

refine mesh sheet [intersect] {node <ids>|edge <ids>} {factor <value>|greater_than <value>} [smooth] [in volume <ids> [depth <num_layers>]]

Inserting sheets

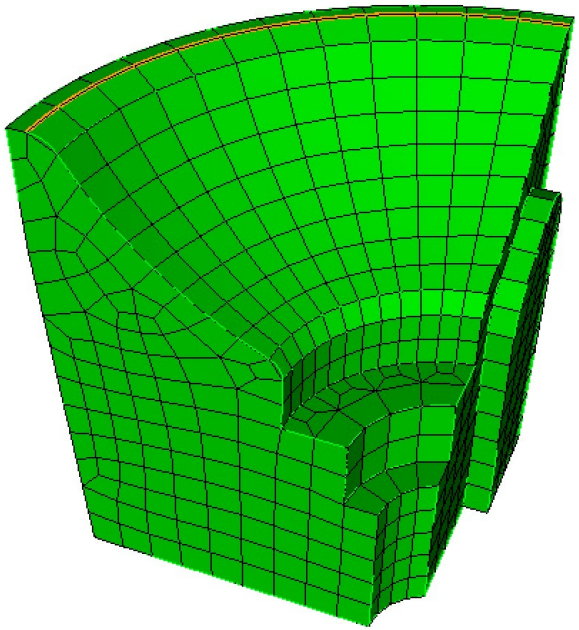
In the Command Panel Select:

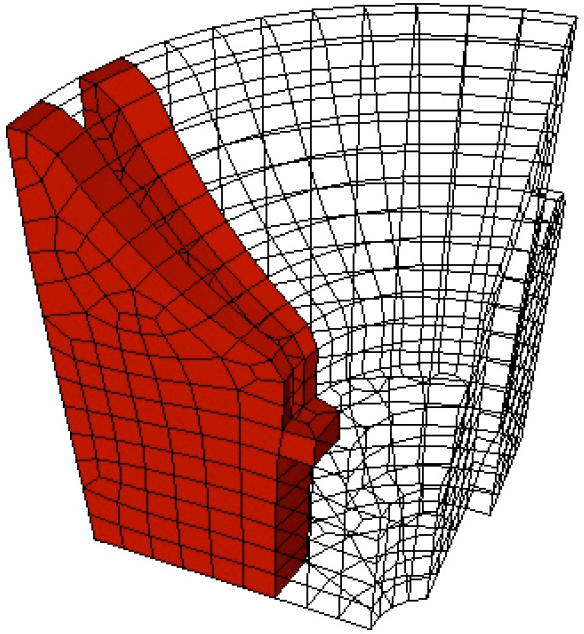
1. Mode – Mesh
2. Entity – Volume
3. Action – Refine
4. Drop Down – Mesh Sheet Refinement



Exercise 5

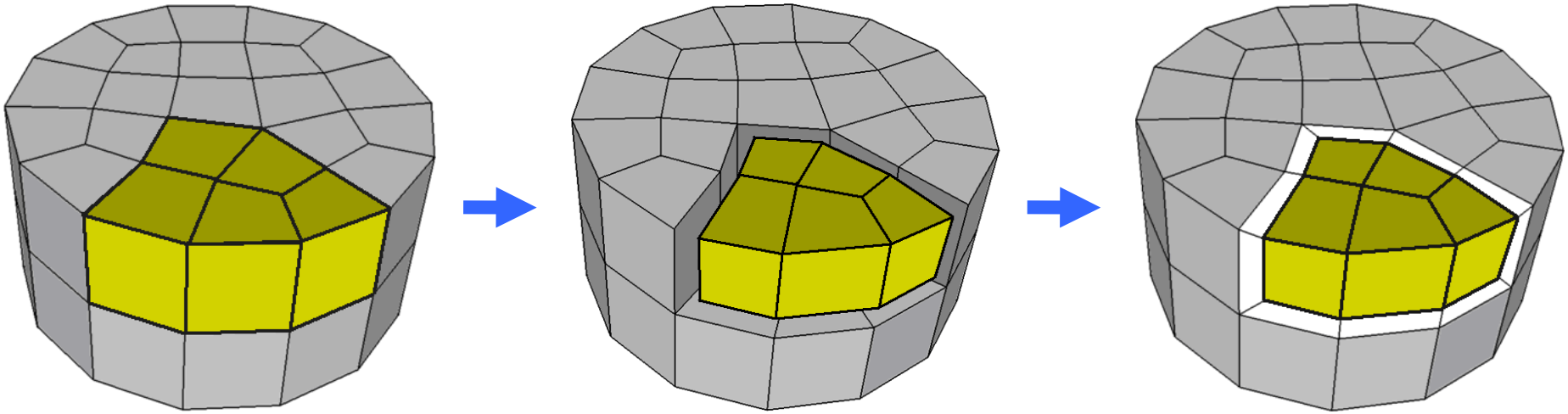
- Import ACIS file "**ra.sat**"
- Mesh the volume with hexes using default options
- Use the mesh sheet refine command to refine high aspect ratio elements greater than **1.0**
- Use the Cubit command: ***draw sheet edge <id> mesh*** to display at least one of the inserted sheets





Pillowing

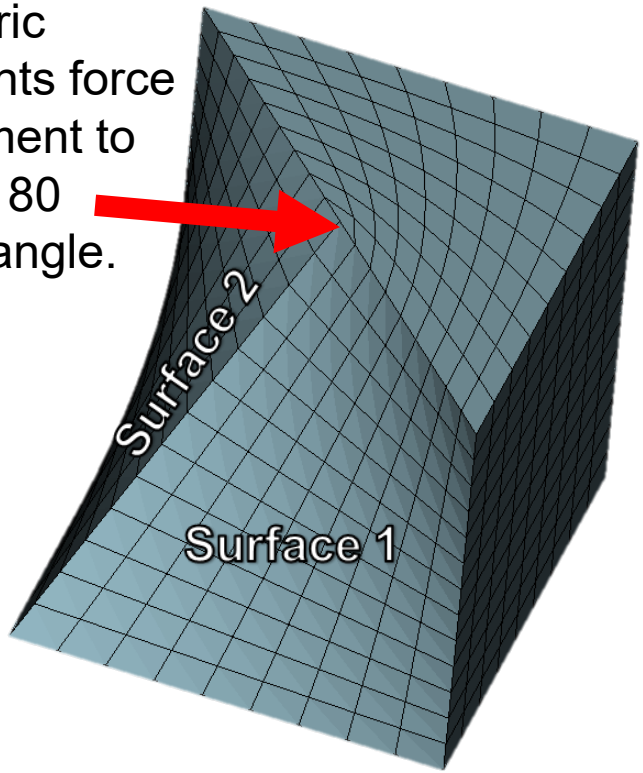
- Pillowing adds a new sheet of hex elements to the mesh, surrounding a user specified set of hexes called the shrink set.



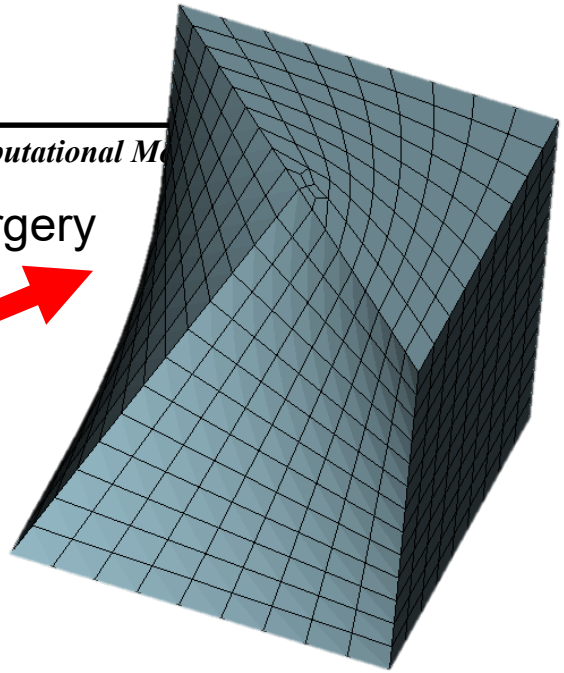
- Cubit Syntax: ***pillow hex <range> through surface <range>***

Pillowing

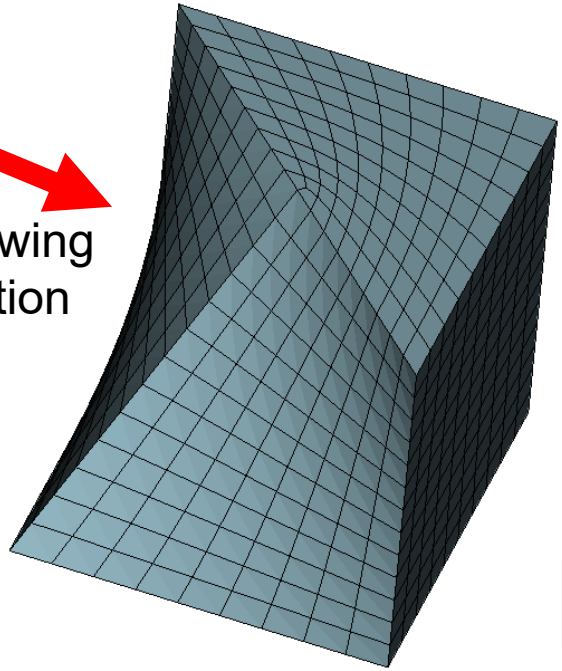
Geometric constraints force this element to have a 180 degree angle.



Mesh surgery solution



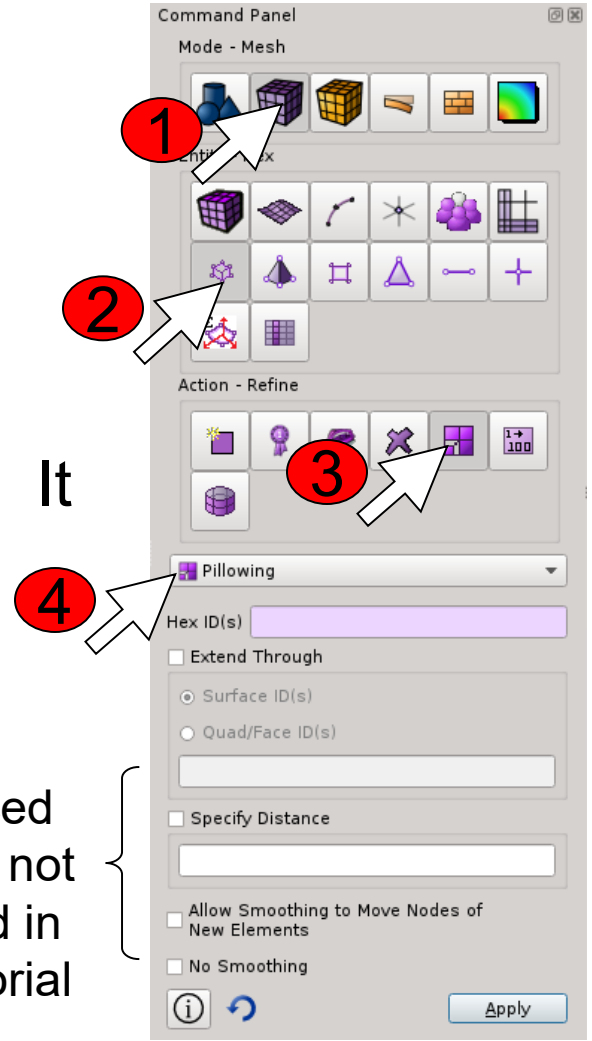
Pillowing solution



Cubit Command:
pillow hex all through surface all except surface 1 2

Pillowing

- You can access pillowing either from the GUI or from the command line.
- The set of hexes to pillow should be strategically chosen to improve element quality.
- The list of hexes can often be quite long. It is often easiest to create a group of the hexes you want to pillow.

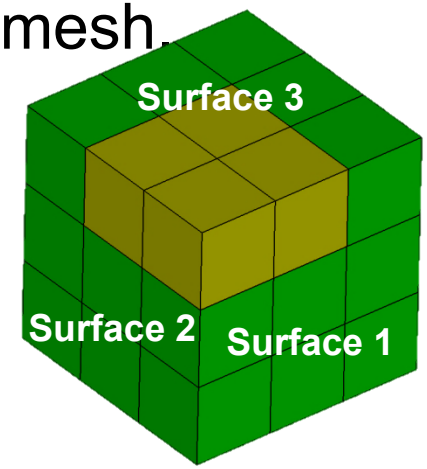


Advanced options not covered in this tutorial

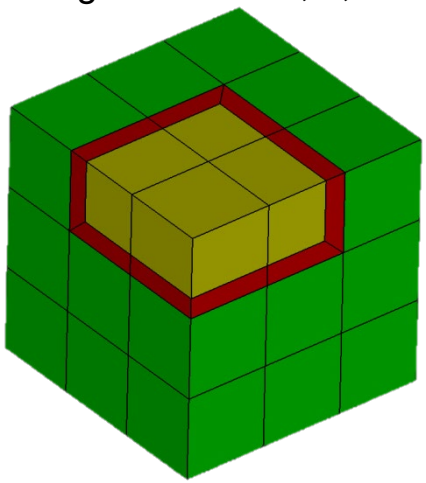
Pillowing

The ***through surfaces*** define how the sheet will exit the boundaries of the mesh.

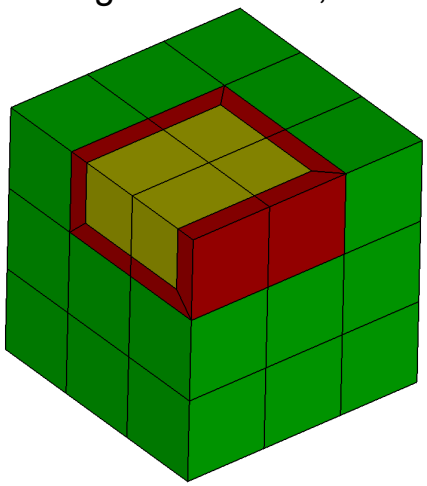
Only the ***through surfaces*** are modified



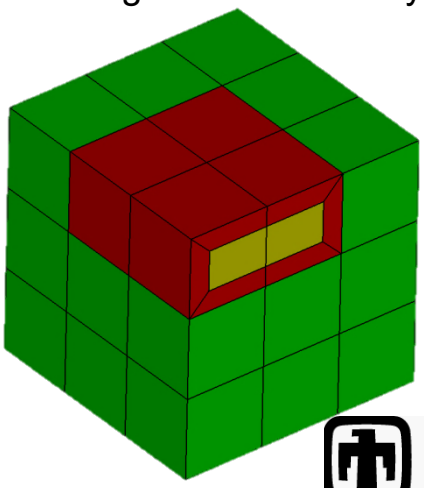
Through surfaces 1, 2, and 3



Through surfaces 2, and 3



Through surfaces 1 only

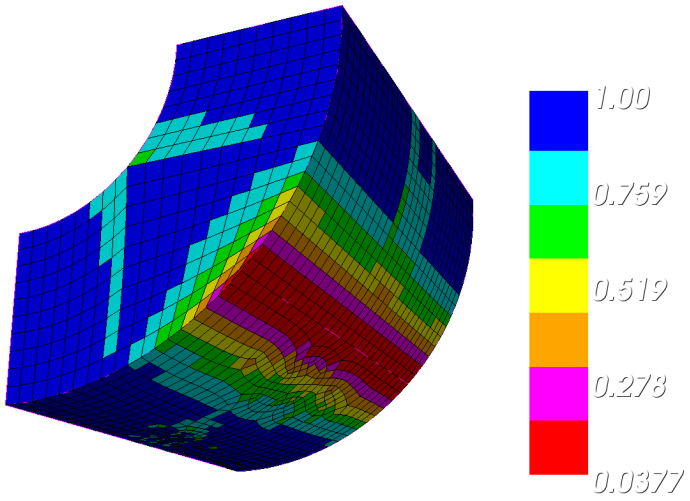


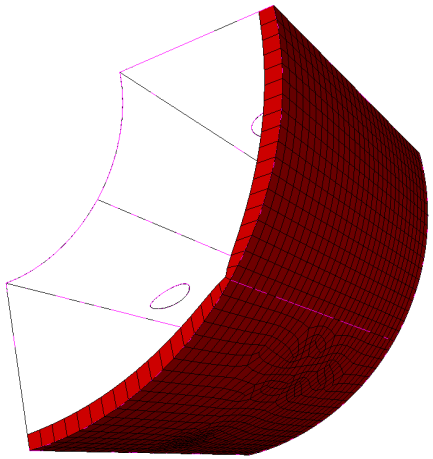
Exercise 5 - Pillowing

- Create a brick "***create brick x 10 y 10 z 10***"
- Mesh it with hexes
- Pillow different groups of hexes experimenting with different through surfaces.

Exercise 6 - Pillowing

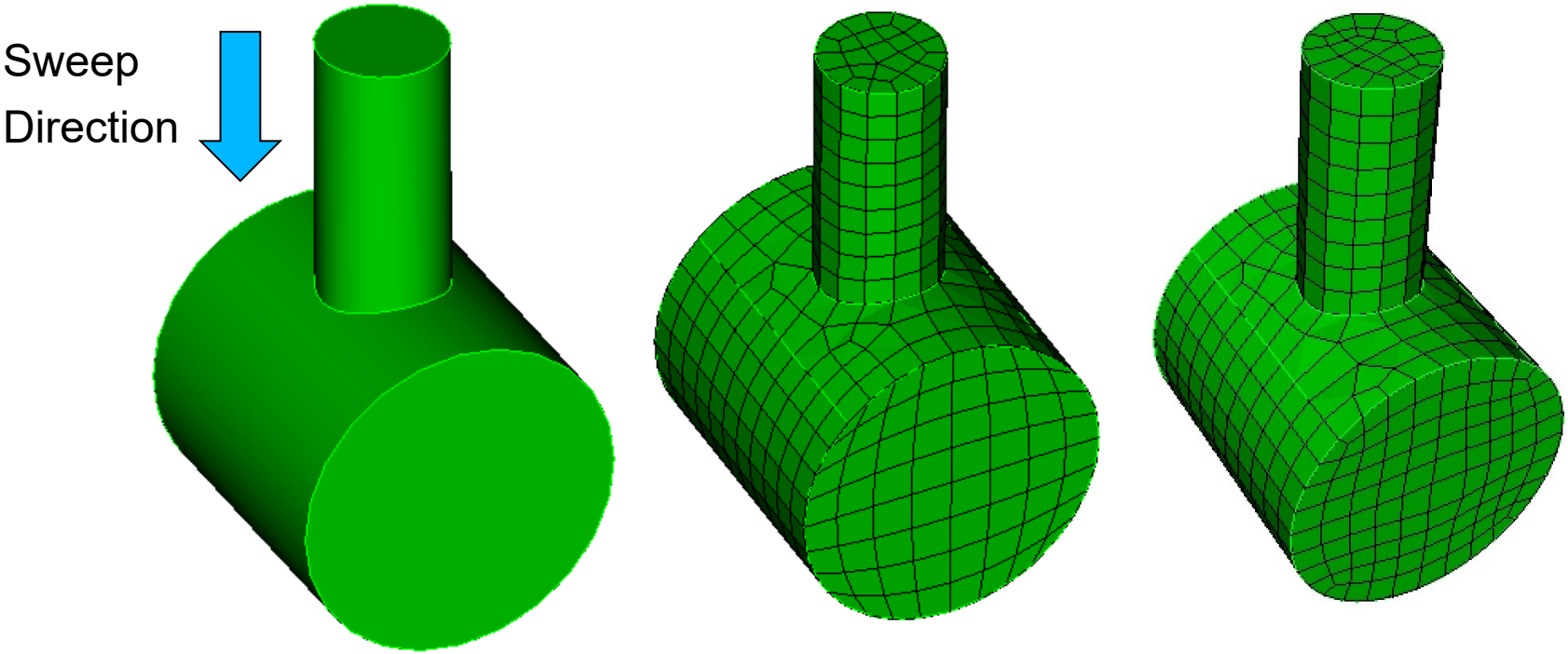
- Open the model “example20_1.cub”
- Do an element quality check. What is the lowest element quality? Why does it have poor element quality?
- Use the pillow surface option in the GUI to insert a pillow adjacent surfaces 34 and 35
- After pillowing use smoothing to improve the quality of the mesh. How high can you raise the quality?
- Draw the new sheet of hexes you added using the ‘***draw sheet edge <id> mesh***’ command. It should look like the drawing below.





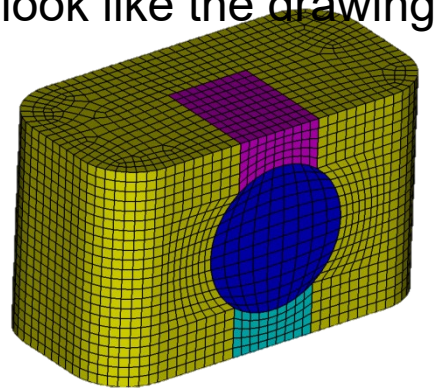
Example 7: Pillowing

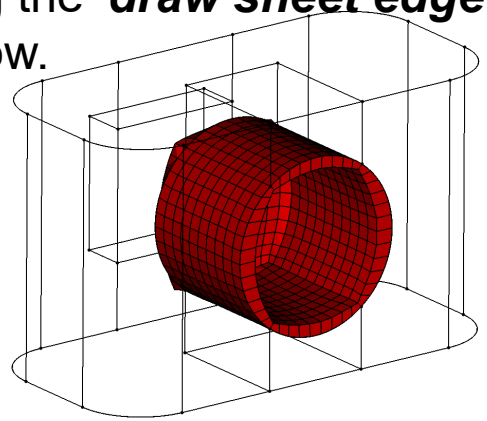
- Open the model “example19_3.cub”
- Use pave-sweep to mesh the volume using the sweep direction indicated
- Insert a layer of hexes using the pillow command to improve the mesh quality



Exercise 8 - Pillowing

- Open the model “example20_2.cub”
- Do an element quality check. What is the lowest element quality? Why does it have poor element quality?
- Create a group of hexes (called “topillow”) to use as the shrink set for pillowing.
- Add all hexes in volume 5 to “topillow”
- Add all hexes that have one of their faces in surface 31 to “topillow”
- Decide which surfaces to use as the ***through surfaces.*** (hint, you should have 2)
- Put in the pillow (hint: ***pillow hex in topillow through surface X Y***)
- After pillowing use smoothing to improve the quality of the mesh. How high can you raise the quality? With a combination of smoothing schemes, you should be able to get the Minimum Scaled Jacobian: 0.5.
- Draw the new sheet of hexes you added using the ‘***draw sheet edge <id> mesh***’ command. It should look like the drawing below.





Exercise 9

- Open the file “ImproveQuality.cub”
- Perform a quality check to see where the bad elements are?
- Why do you think there are bad elements?
- Use a combination of uniting meshed volumes, smoothing, and mesh surgery to improve the quality of the mesh. You should be able to get the Min Scaled Jacobian metric up to about 0.24, from the original value of 0.03.
- Avoid just uniting all of the volumes together. Instead, choose just a subset of the volumes in the model to do the unite meshed volumes command on.