998 Good Bricks : Hex Meshing Core Concepts & Efficient Workflows

May 19th, 2022

A Simcenter Femap Seminar for Simulation Engineers

Presented by Geoffrey Bee, PE - Application Engineer, CAE

2022 Simcenter Symposium

Thursday, June 16th, 2022
Seattle, Washington
The Museum of Flight (South View Lounge)

The Simcenter Symposium in Seattle, Washington, is an opportunity for new and current Simcenter Femap, STAR-CCM+, and Simcenter 3D users to gather for a day of technical training and networking with peers, industry experts, solution experts, and Siemens product development team members. Whether you are a simulation engineer, analyst, manager or executive, don't miss out on this exclusive event.

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Agenda

9:00 am	Introduction: the Siemens Simulation Portfolio overvie w
9:30 am	WhatÕsnew in Simcenter Femap
10:45 am	Simcenter Femap 2022: Deep Dive - Meshin g
11:15 am	Automation with the Femap AP I
11:45 am	Catered lunch, provide d
12:30 pm	Simcenter Femap Developer Roundtable
1:30 pm	Improved hypersonic simulations with Simcenter STAR-CCM +
2:00 pm	Integrated Design Optimization with Simcenter STAR-CCM +
2:45 pm	Simcenter 3d (Topic TBA)
3:30 pm	Customer success story: AeroTE C
4:00 pm	Happy hour

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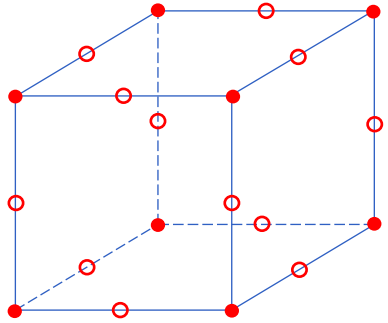
Hex Meshing Core Concepts & Efficient Workflows

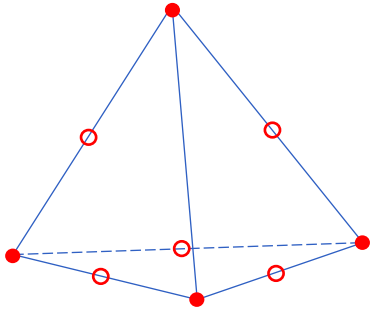
- What is a Hex, or Hexahedral, Element
- Why Use a Hex Mesh
- Solid Preparation
- Mesh Control Explorer
- Downsides / Precautions

What is a Hexahedral Element

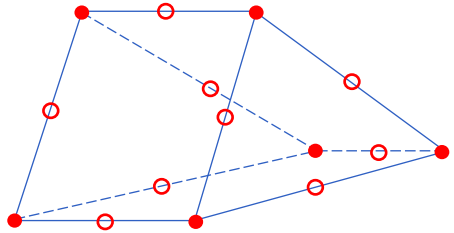
- Hex Element (CHEXA) — Six-sided solid element
  - 8 or ●+○ 20 grid points



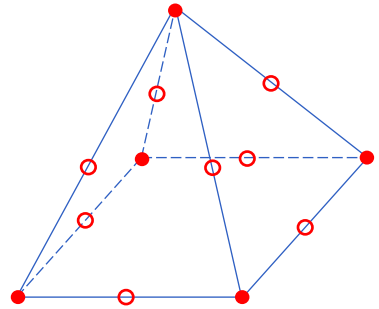
- Tet Element (CTETRA) — Four-sided solid element
  - 4 or ●+○ 10 grid points



- Wedge Element (CPENTA) — Five-sided solid element
  - 6 or ●+○ 15 grid points



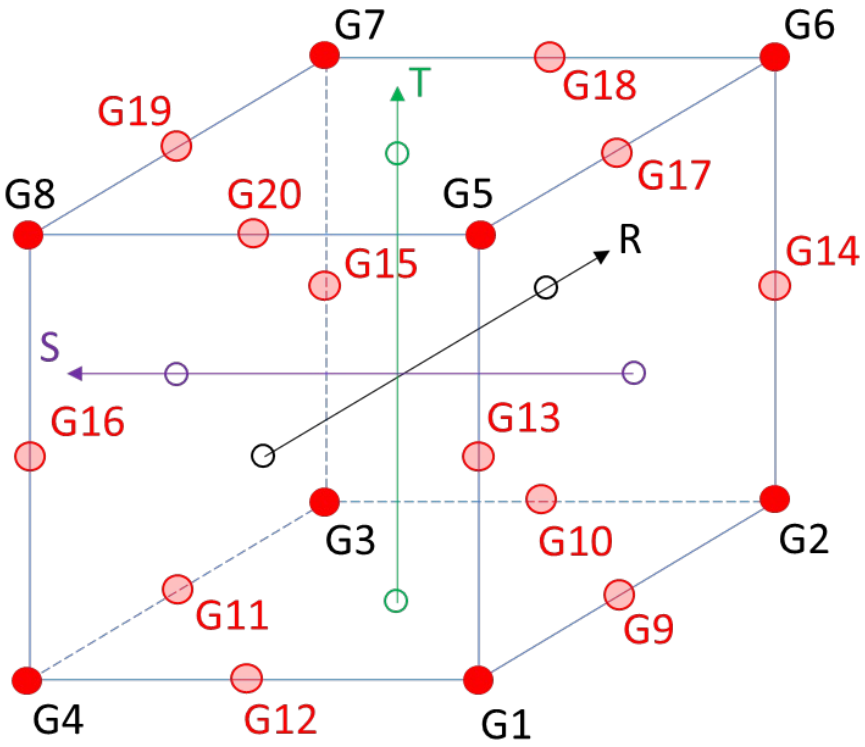
- Pyramid Element (CPYRAM) — Five-sided solid element
  - 5 or ●+○ 13 grid points



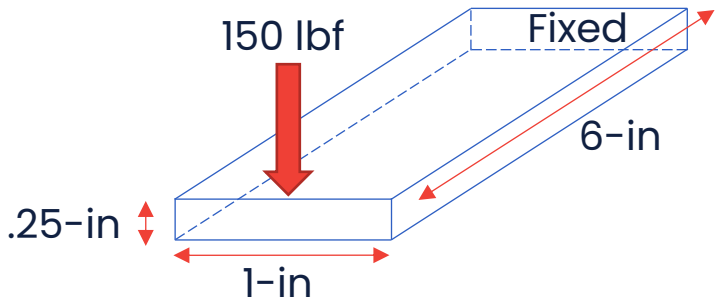
What is a Hexahedral Element

Six-Sided Solid Element (CHEXA) Element

- 8 Corner Grid Points
- Up to 20 Grid Points if 12 Optional Midside Grid Points Included
- Like all solid elements, hex elements have only translational degrees of freedom. No rotational DOF are used to define solid elements.
- Stress is calculated at element's Gauss points. These stress values are then interpolated to the centroid and extrapolated to the nodes.
- The CHEXA element coordinate system is defined in terms of vectors R, S, and T which join the centroids of opposite faces
- The origin of the coordinate system is located at the intersection of these three vectors

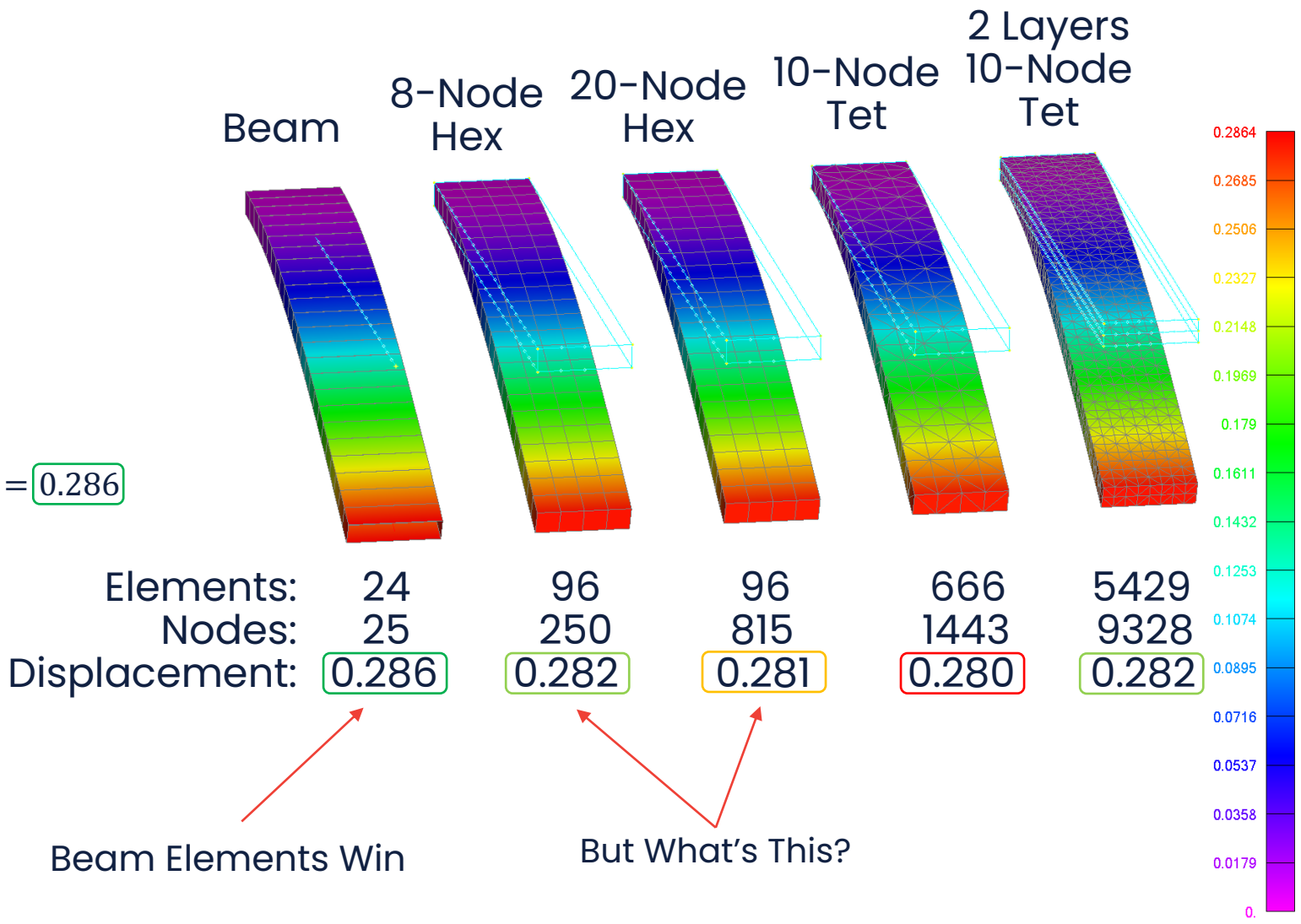


Why Use a Hex Element: Accuracy



$$Tip\ Deflection = \frac{PL^3}{3EI}$$

$$Tip\ Deflection\ (in) = \frac{150 * 6^3}{3 * 29{,}000{,}000 * 0.00130208} = \boxed{0.286}$$

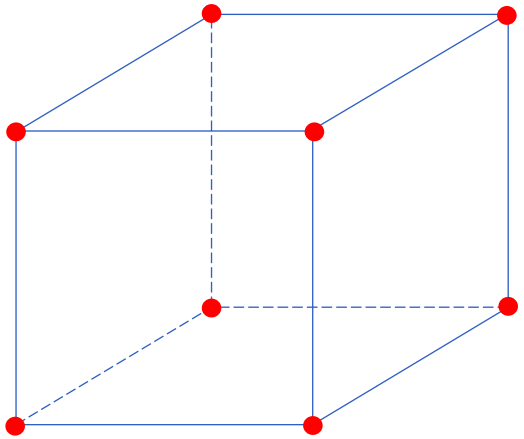


Elements:	24	96	96	666	5429
Nodes:	25	250	815	1443	9328
Displacement:	0.286	0.282	0.281	0.280	0.282

Beam Elements Win

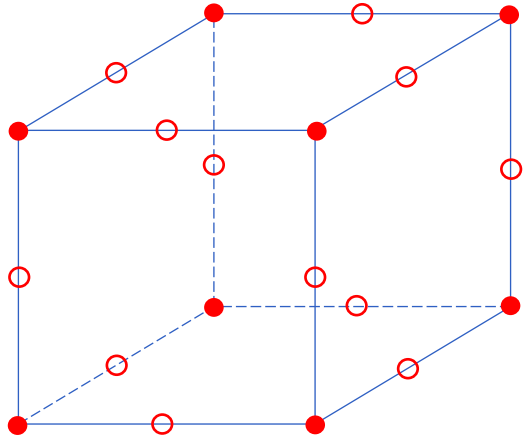
But What's This?

Advantages of Hex Meshing: Accuracy Sidenote



8-Node Hex

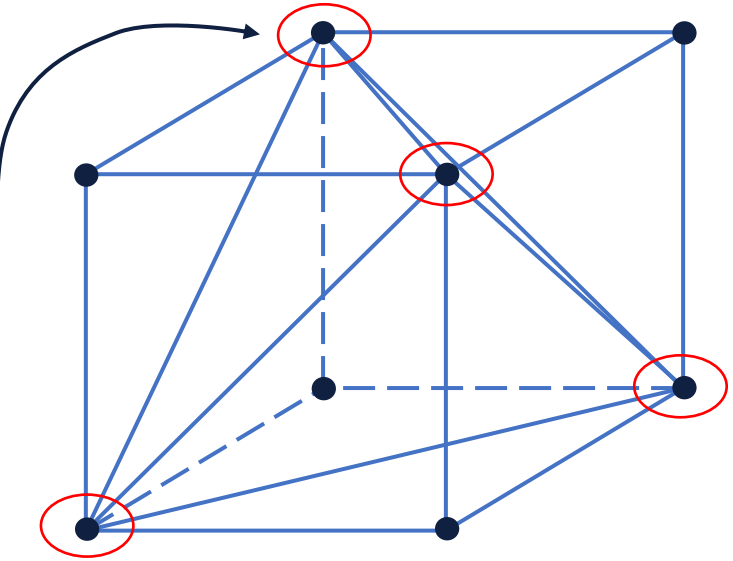
\+ Wilson incompatible shape functions + Volumetric locking alleviation function ≈



20-Node Hex

Advantages of Hex Meshing: Accuracy

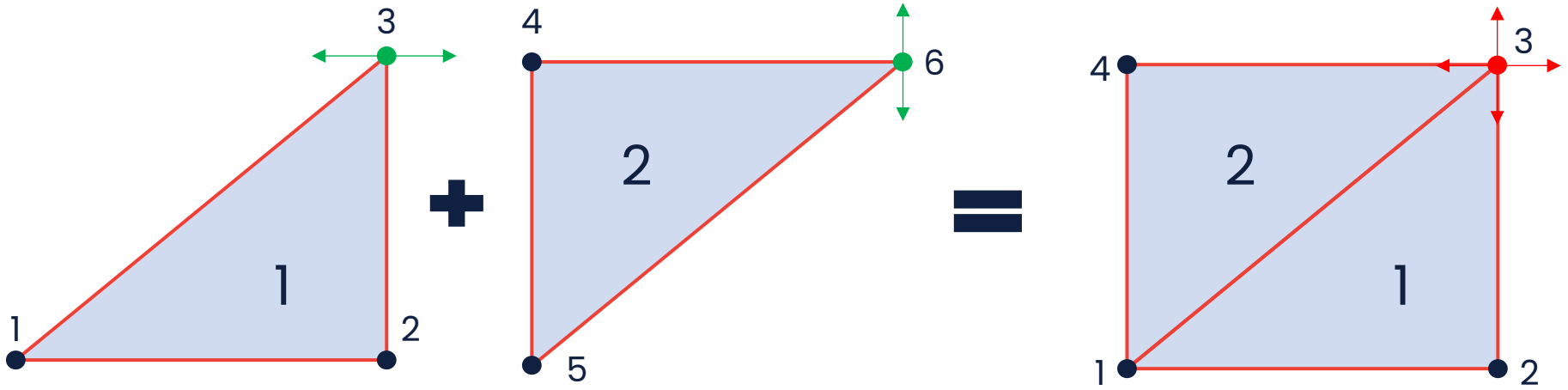
- Hex elements exhibit superior performance in bending and torsion.
- Tet meshes inherently have poorer aspect ratios and nodes with high valence, which artificially increase the overall stiffness of the finite element model
- Hex elements do not suffer from nonphysical stiffness due to “mesh-locking” to the same extent as equivalent tet meshes for large-deformation and non-linear elasto-plastic structural analyses.



There are 3 elements contributing information to this one node

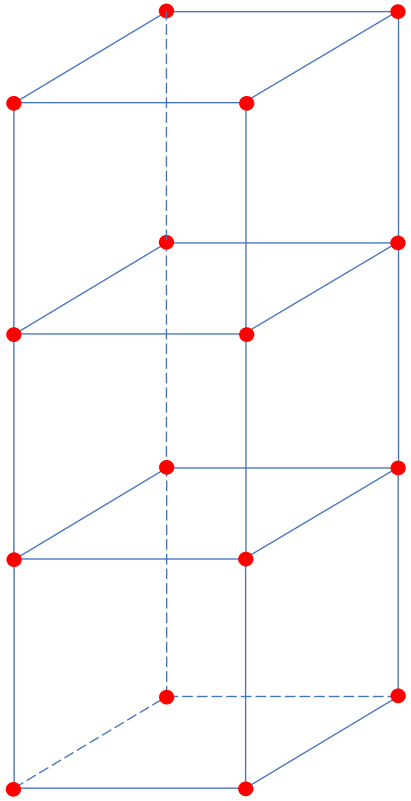
Constant Area

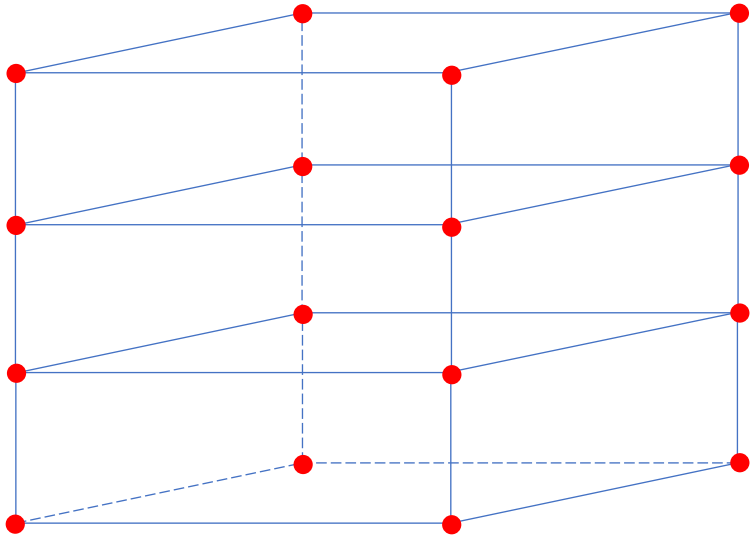
Fixed Node



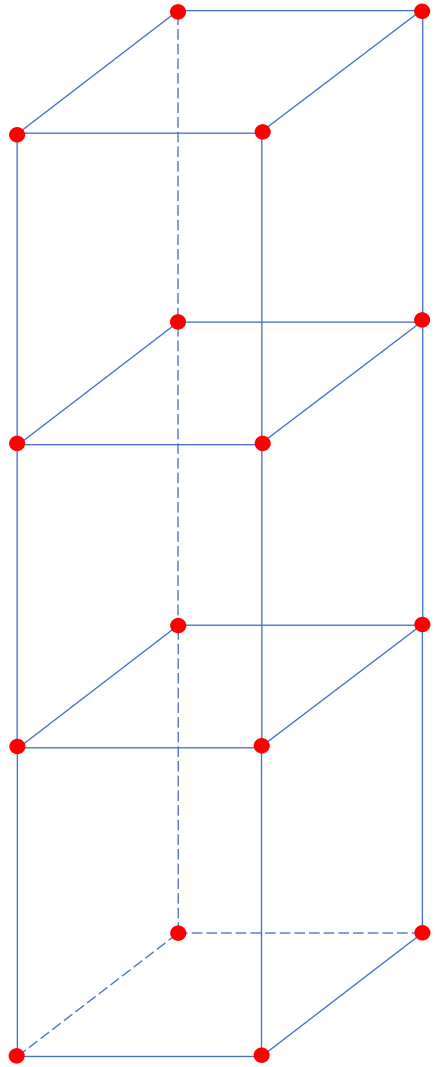
Advantages of Hex Meshing: Accuracy

Their layered structure facilitates anisotropic stretching in the row or column directions without degrading the numerical quality of the mesh.



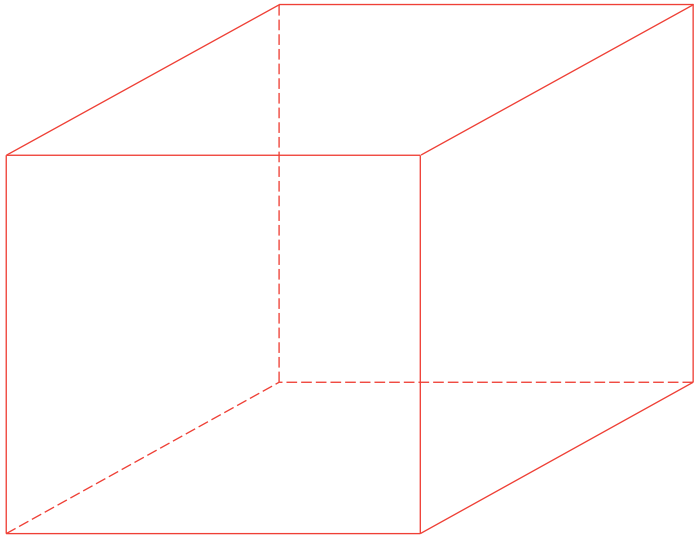


Row Stretching

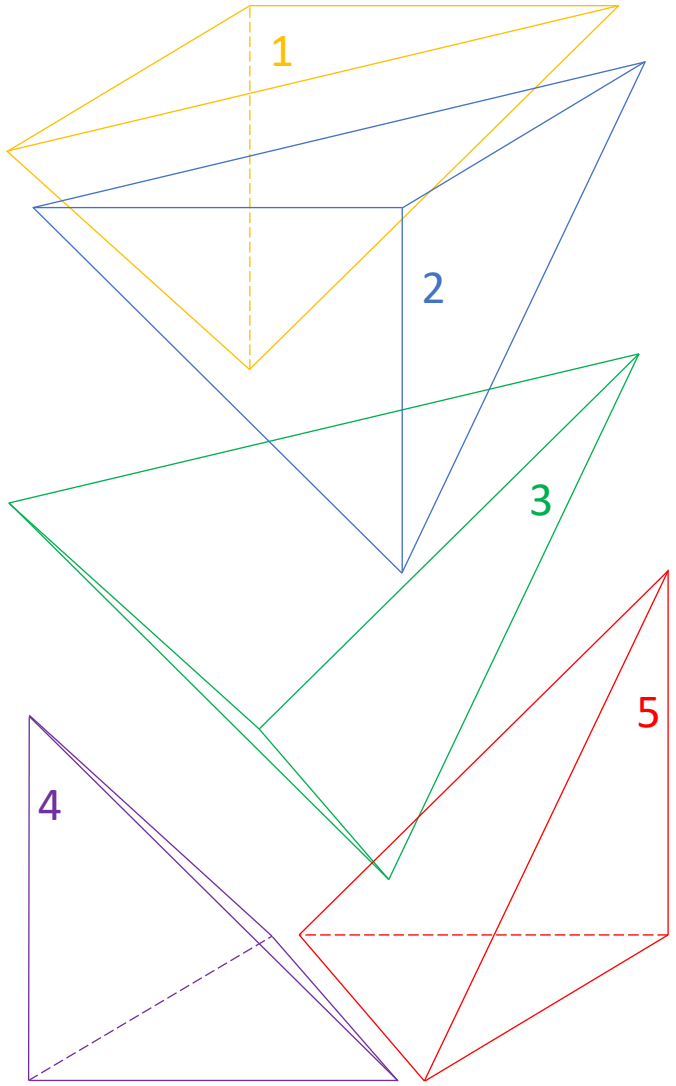


Column Stretching

Advantages of Hex Meshing: Speed



One Hex Element



Five Tet Element

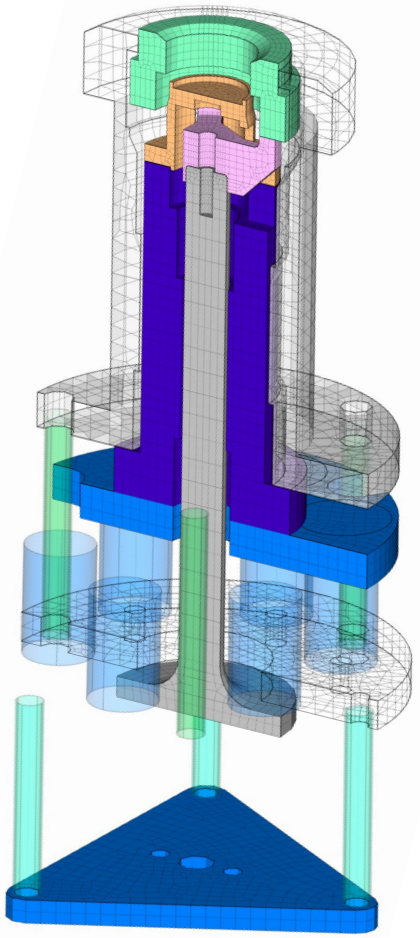
Solid Preparation: Steps

1. Subdivide your model into hex meshable parts.

2. Determine and set the appropriate hex mesh size.

3. Verify that all solids are “hex meshable” and are properly linked to adjacent solids. If not, return to step 1, and continue dividing your solids.

4. Verify element quality.

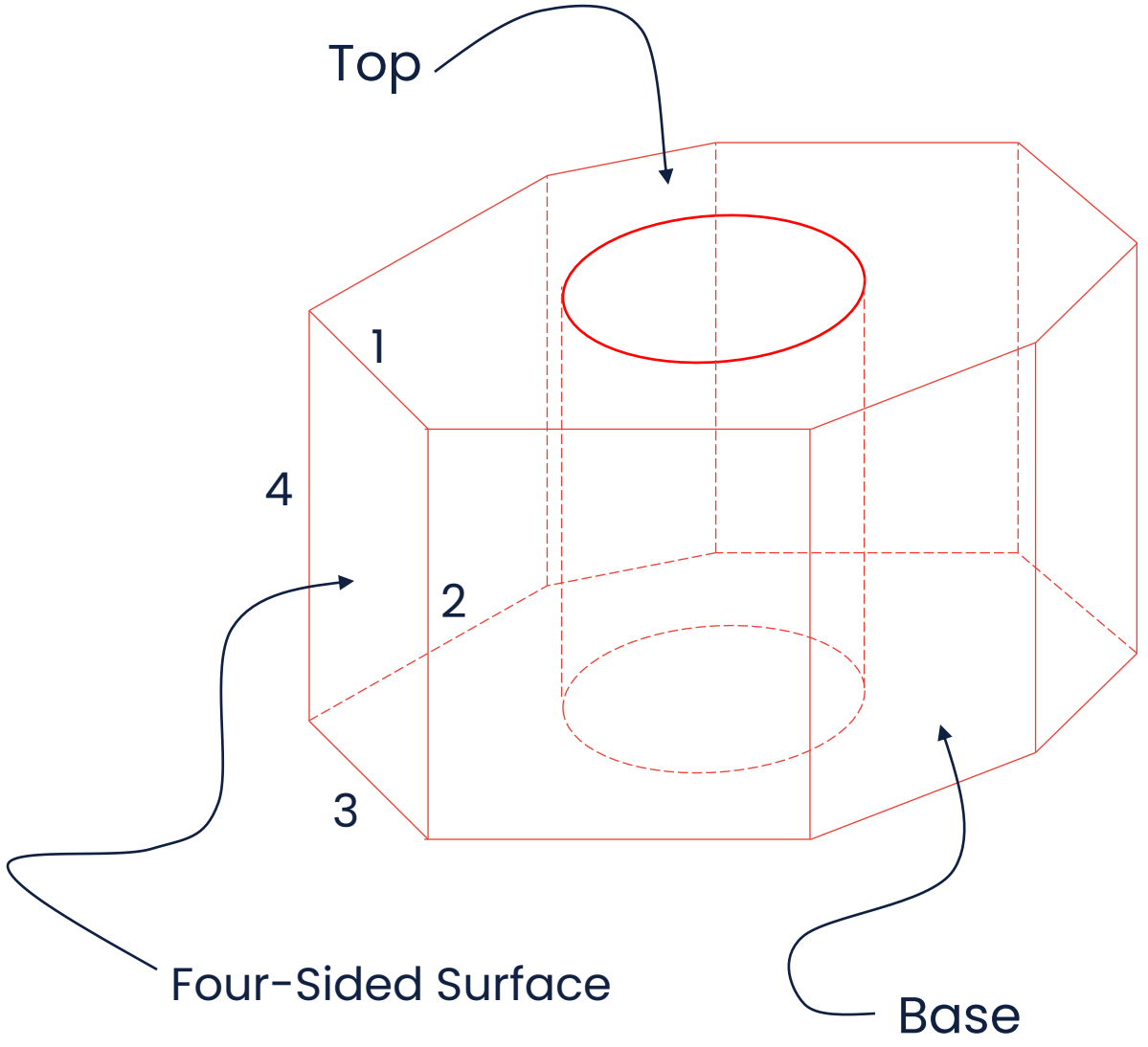


Solid Preparation: Anatomy

FEMAP can only hex mesh “extrudable” or “sweepable” solids. If your part is complex, you must slice it into simpler solids that can be hex meshed.

FEMAP can mesh solids where it can identify a “base” and “top” surface that are connected by four-sided surfaces.

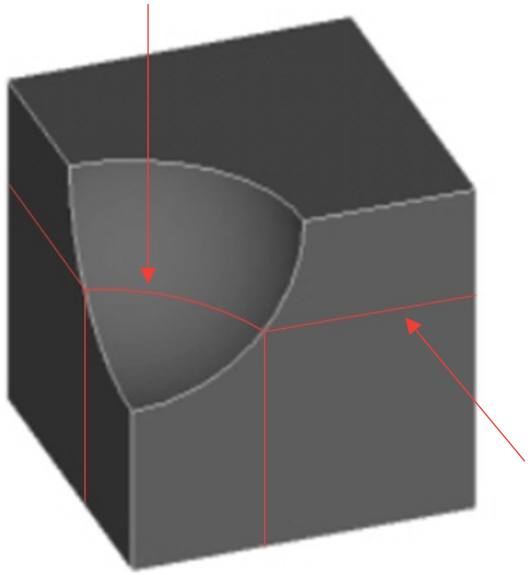
- The base and top surface can be any shape and can include holes.
- The base and top surfaces must have the same number of edges.
- The base and top surfaces must produce a mesh with the same number of nodes, elements, and connectivity. The elements can differ in size.



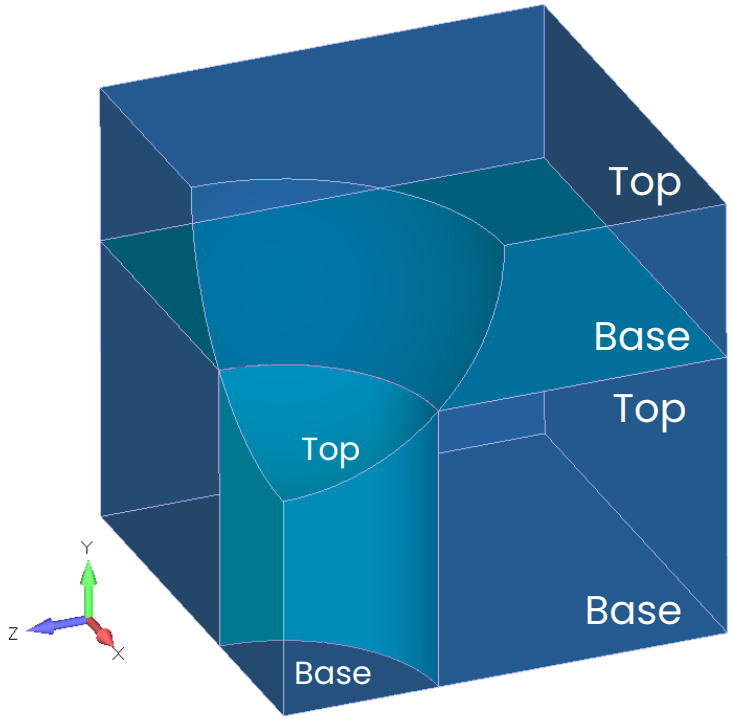
Solid Preparation: Mechanics

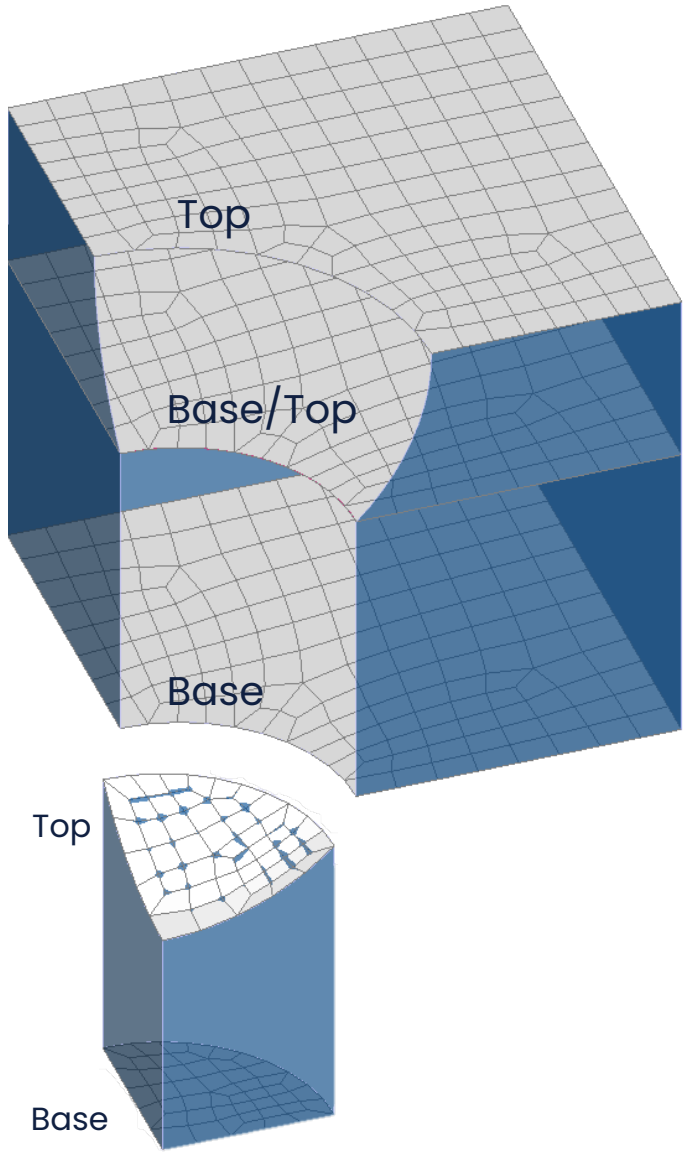
FEMAP identifies the base and top surfaces and automatically matches the mesh on the two surfaces.

Solid Slice with Curve



Solid Slice with Plane

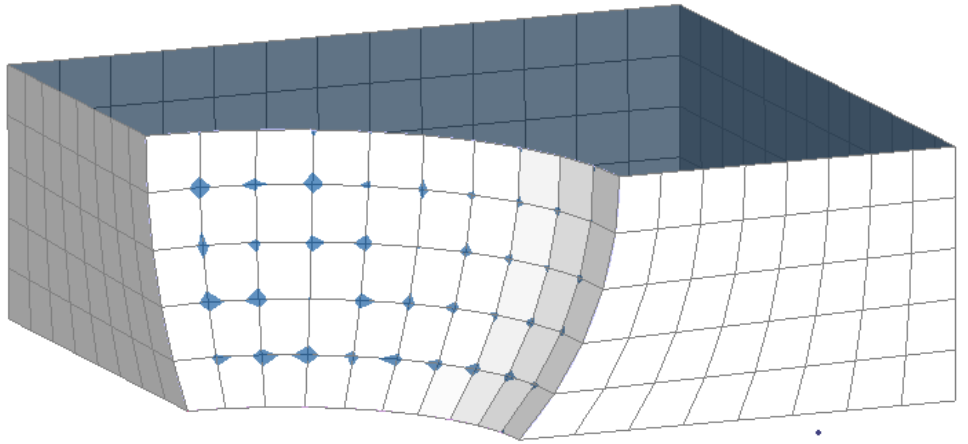


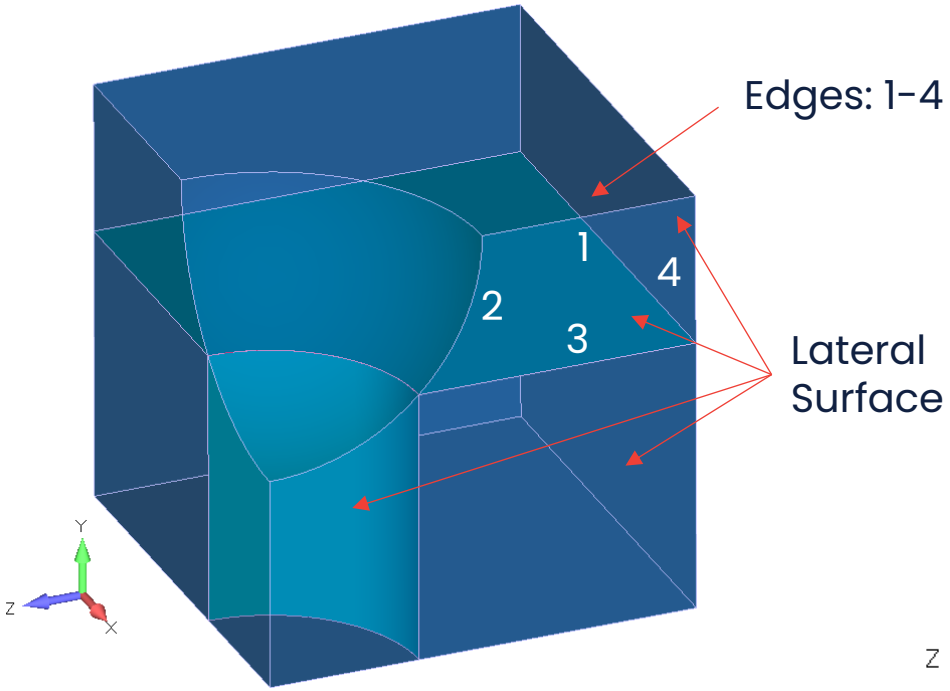


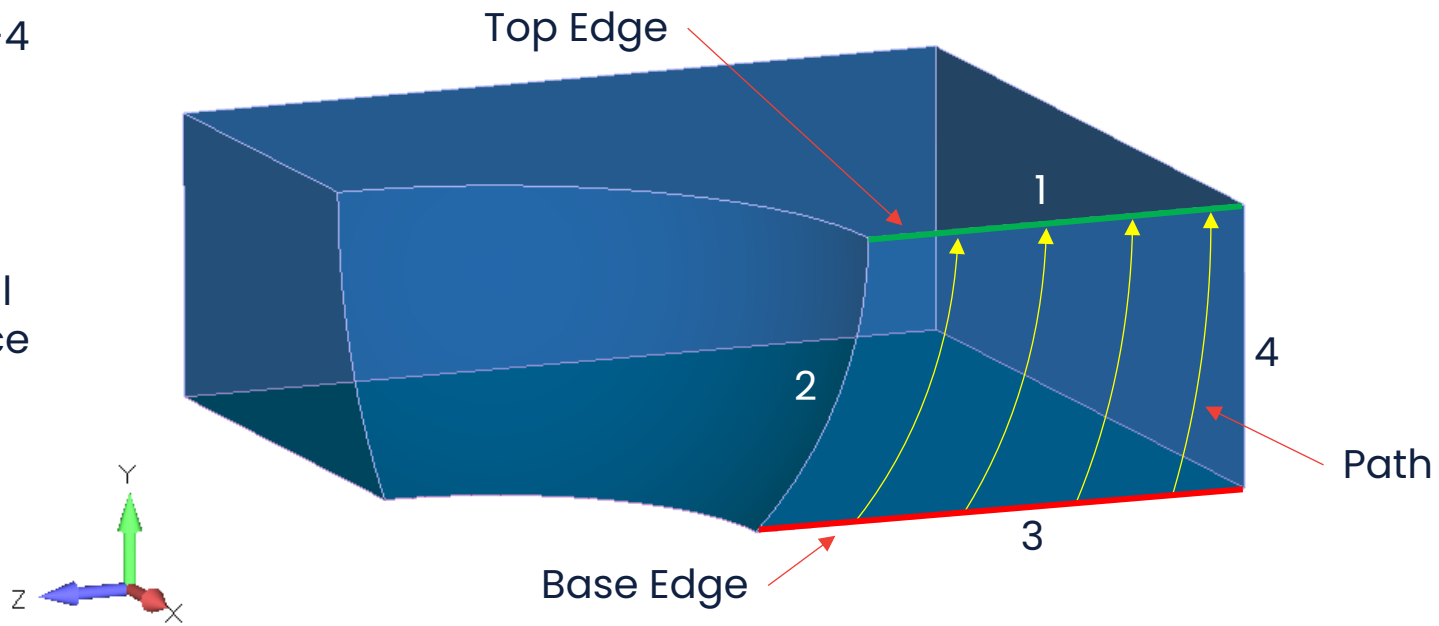
Solid Preparation: Mechanics

The side surfaces control the mesh along the length of the extrusion or sweep.

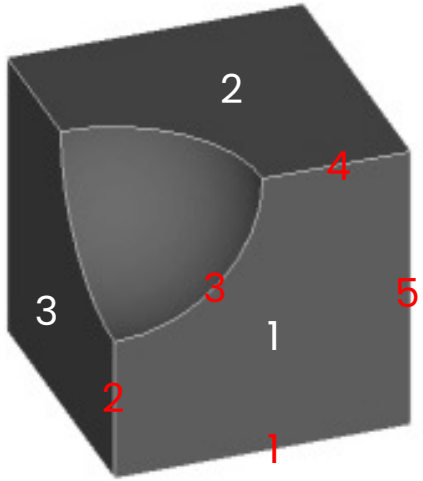
There must be a single “path” through the lateral surfaces from each edge of the base surface, to a corresponding edge on the top surface.



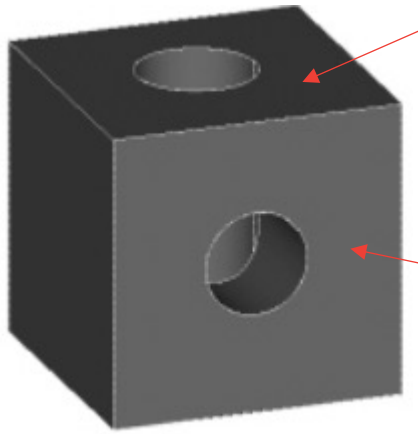




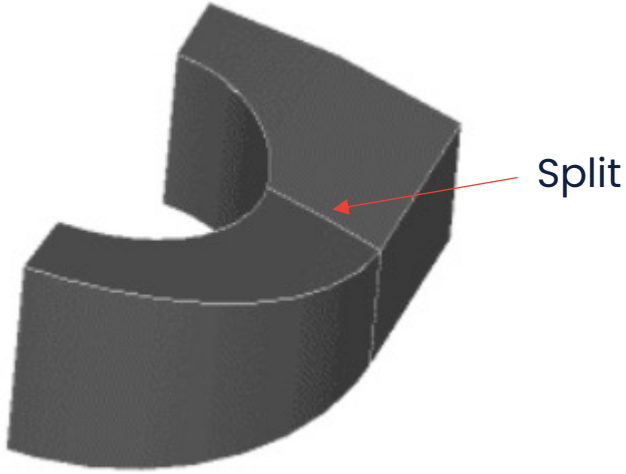
Solid Preparation: Examples



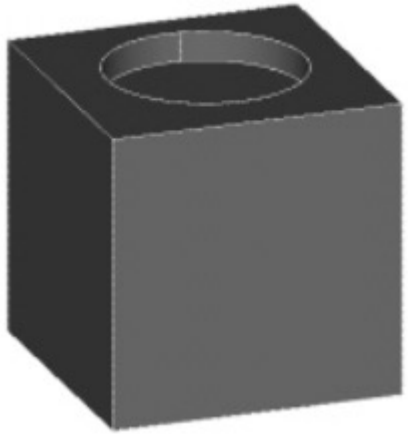
Three Five-Sided Faces



Holes in Faces Other than Base and Top

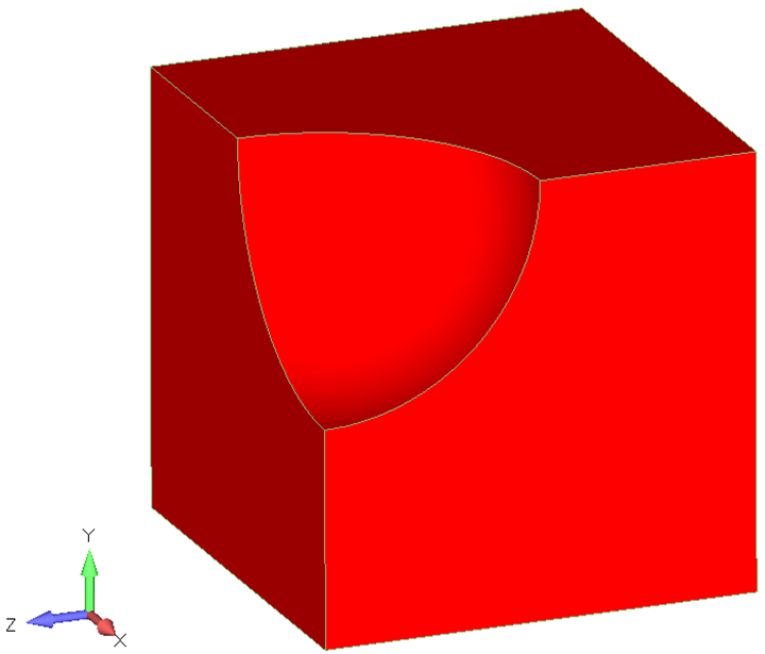


Split Prevents Identification of Top and Bottom

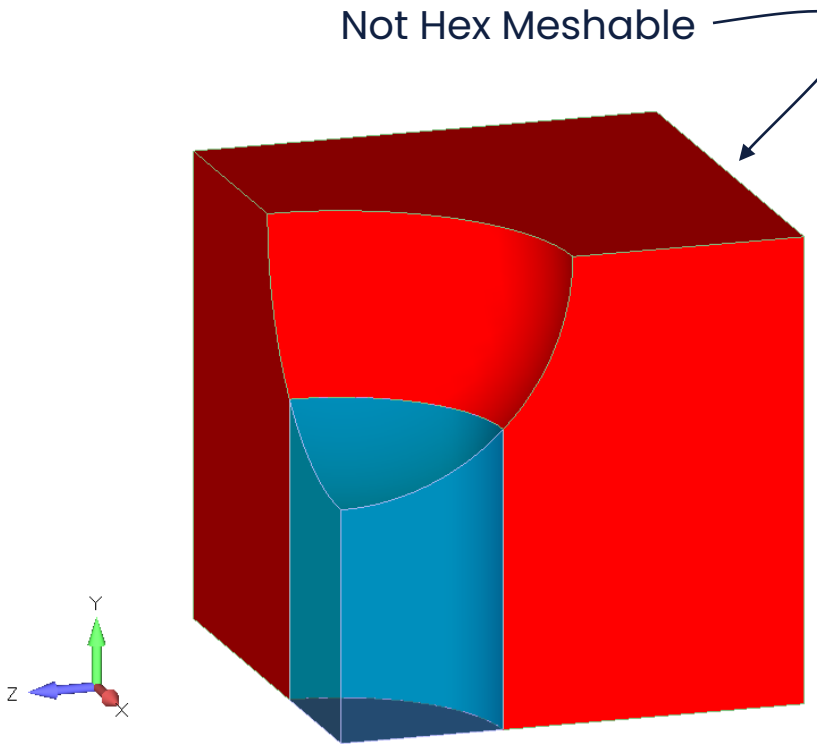


Partial Depth Hole not Embedded Through Solid

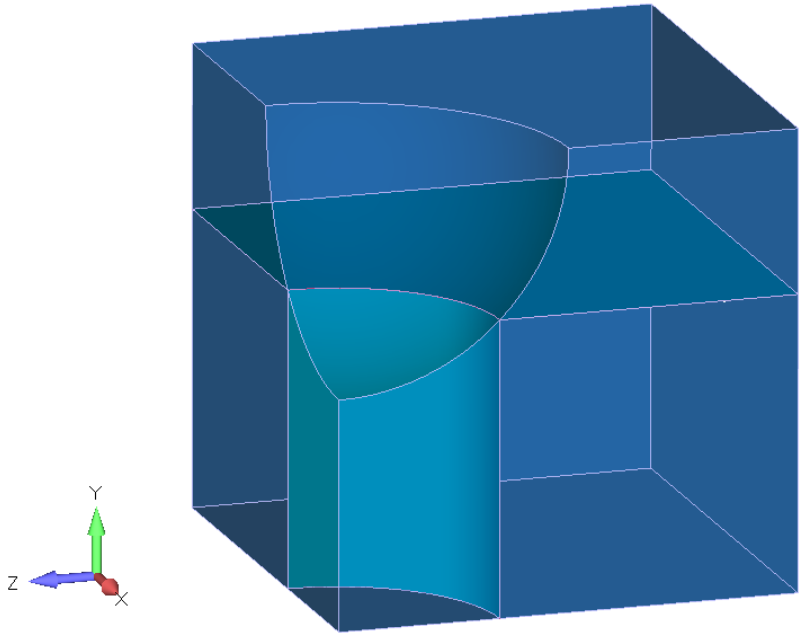
Solid Preparation: Examples



Not Hex Meshable



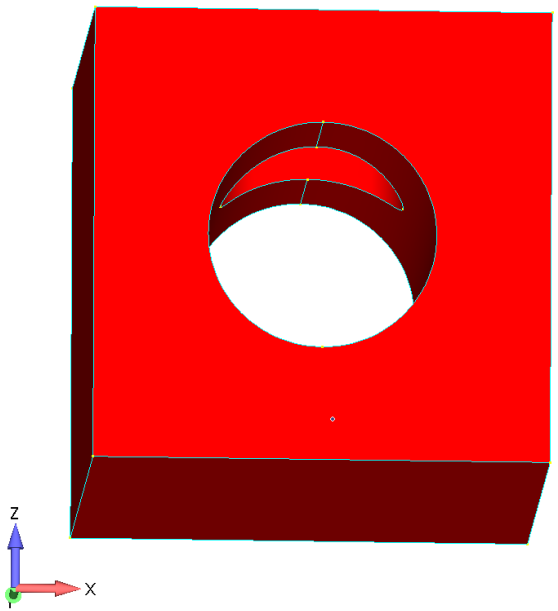
After First Slice



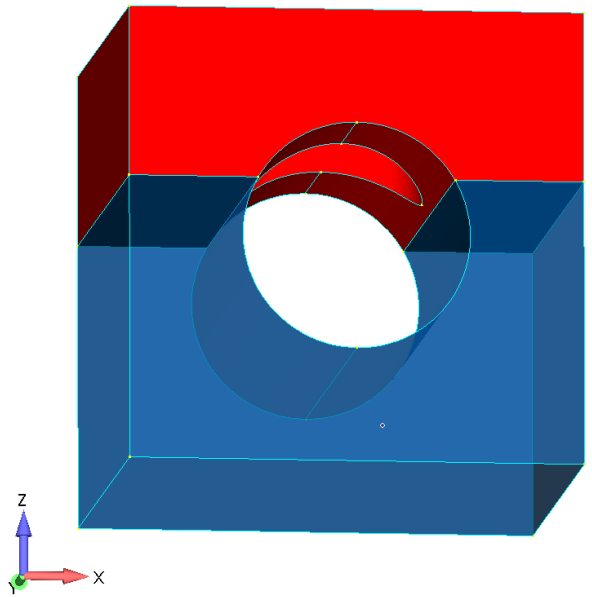
Hex Meshable!

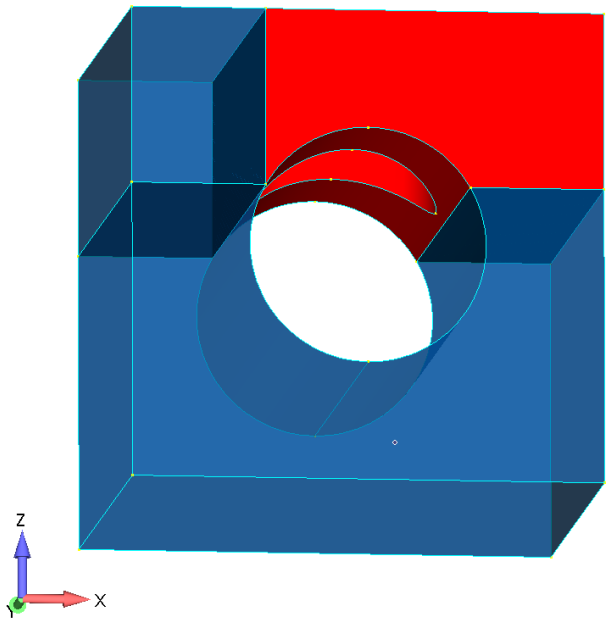
After Second Slice

Solid Preparation: Examples



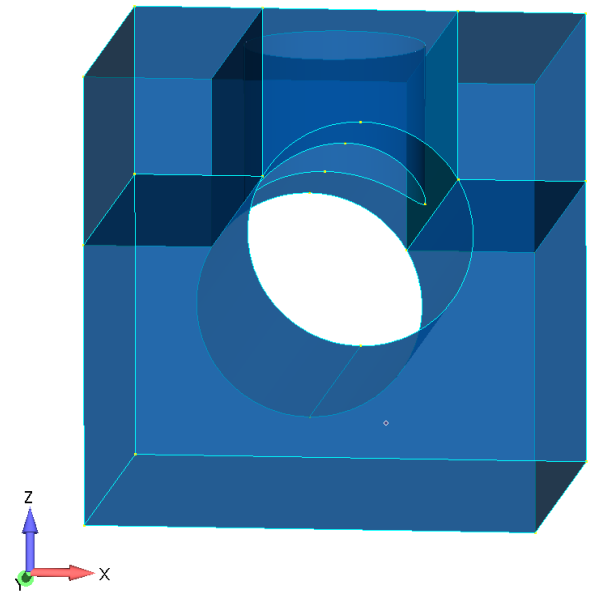
After First Slice



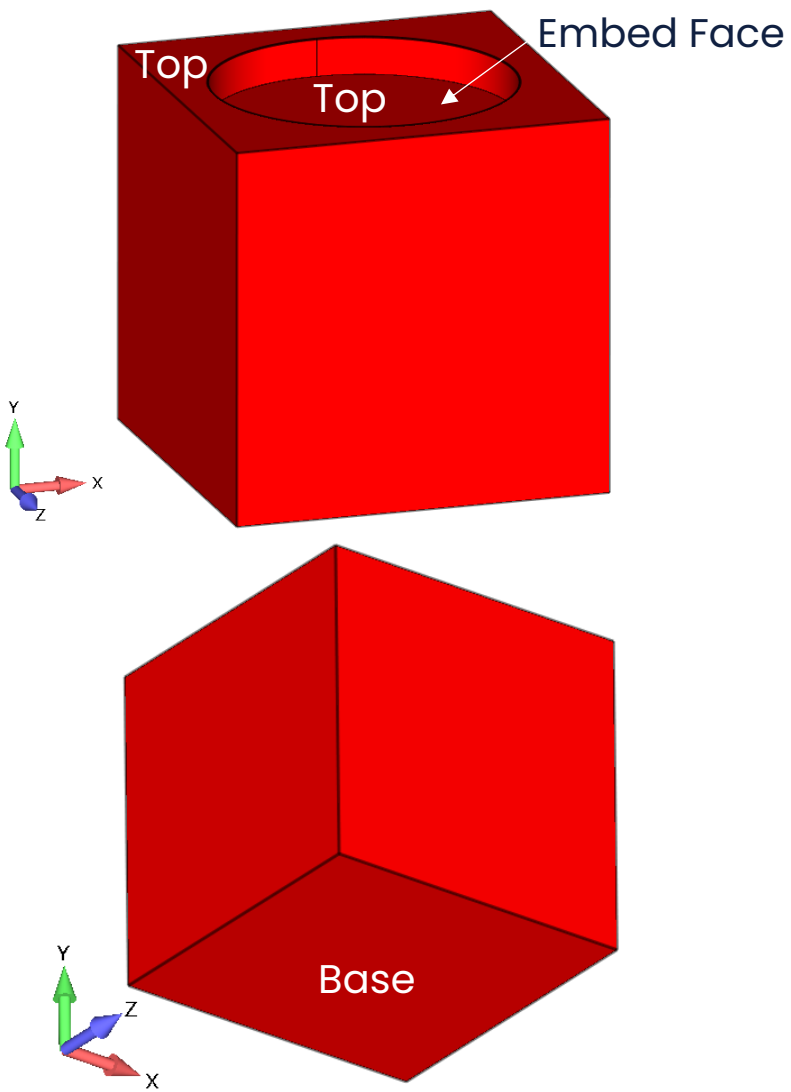


After Second Slice

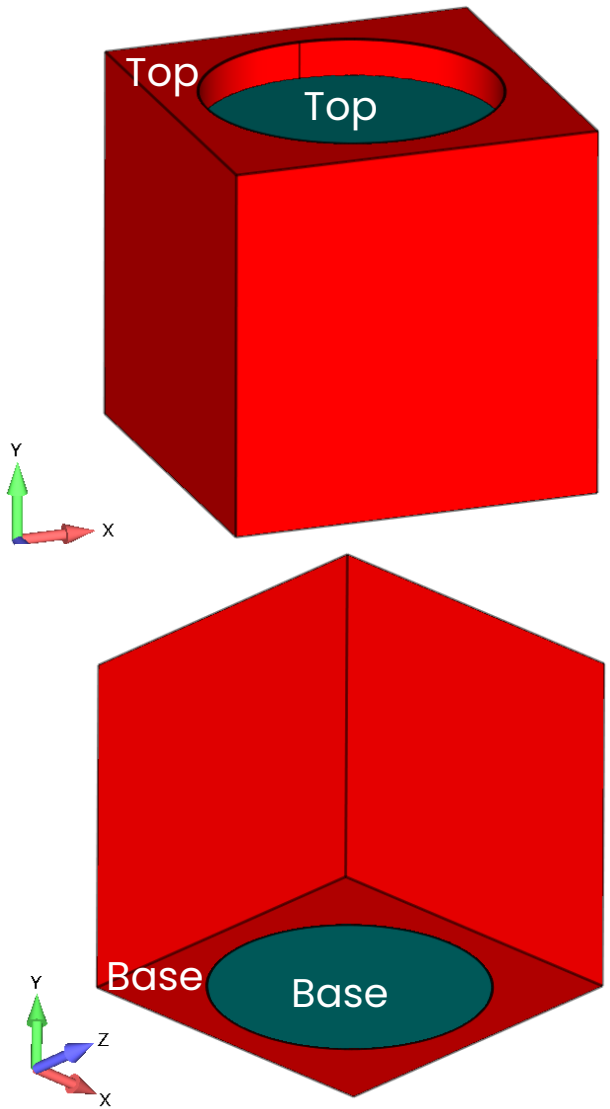
After Third Slice

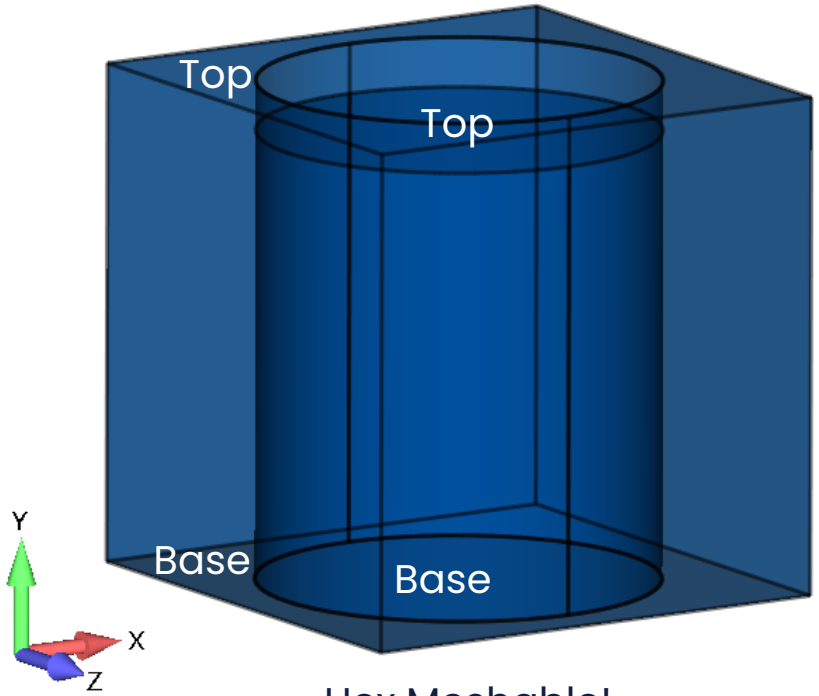


Solid Preparation: Examples



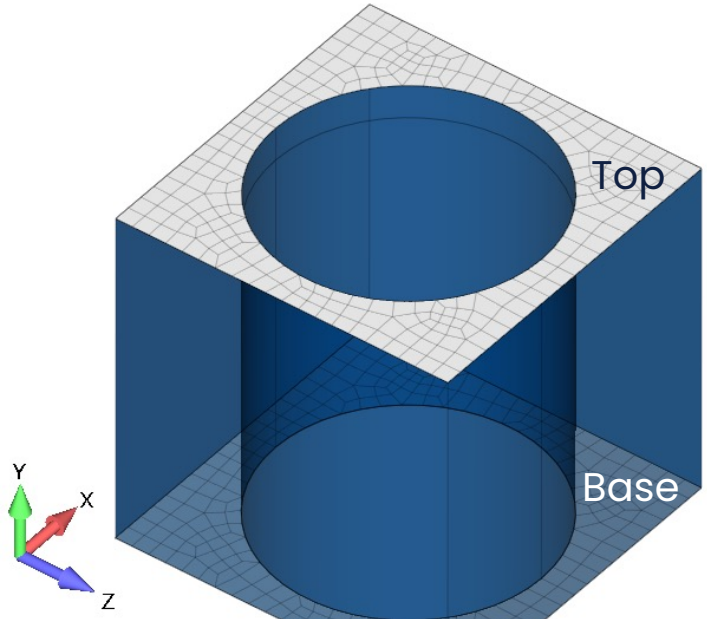
Not Hex Meshable

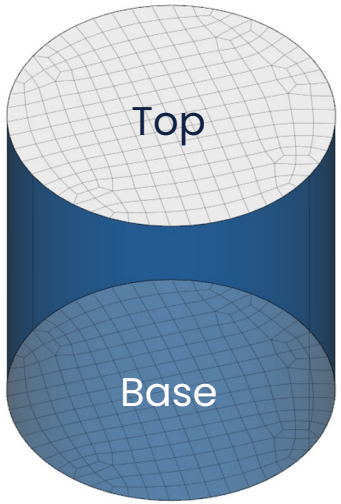


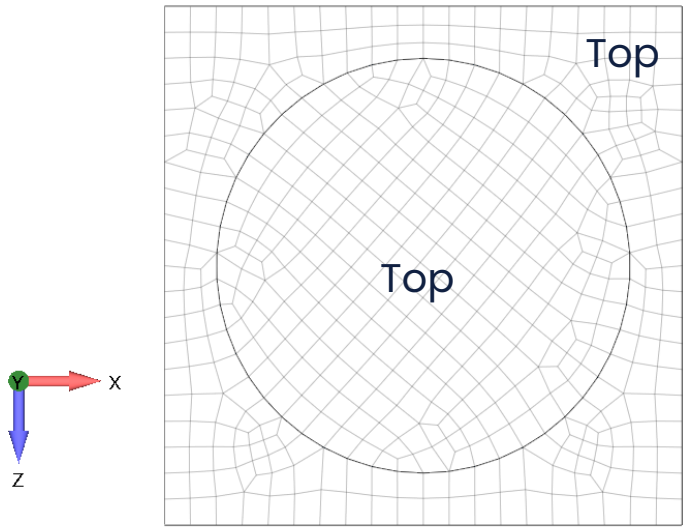


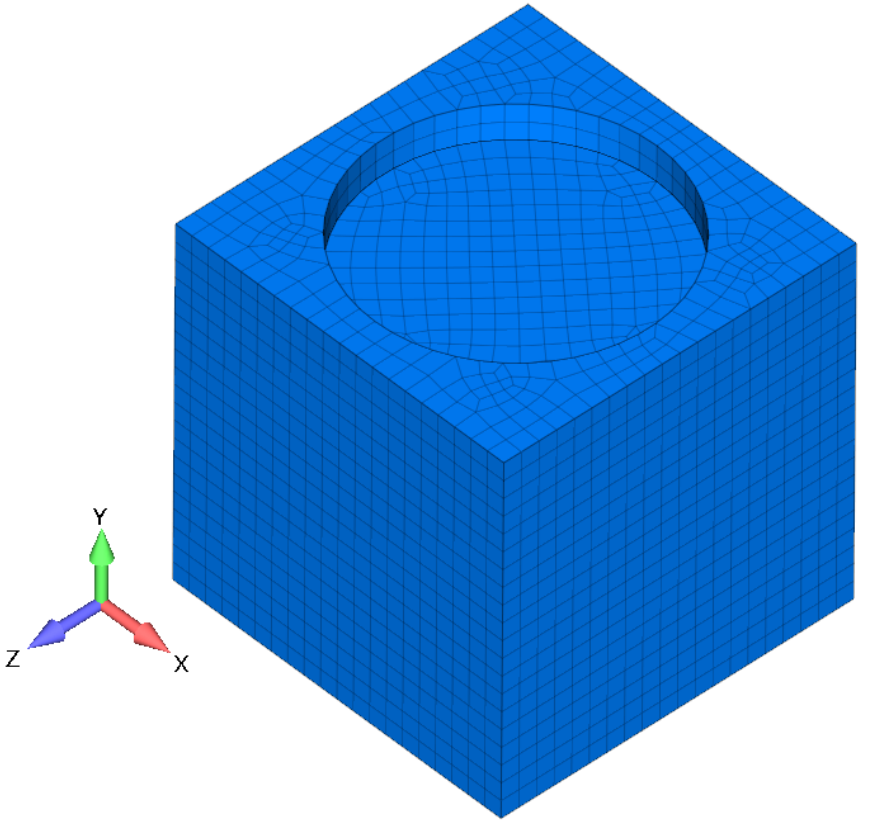
Hex Meshable!

Preparation of Non-Hex Meshable Solids









Disadvantages of Hex Meshing

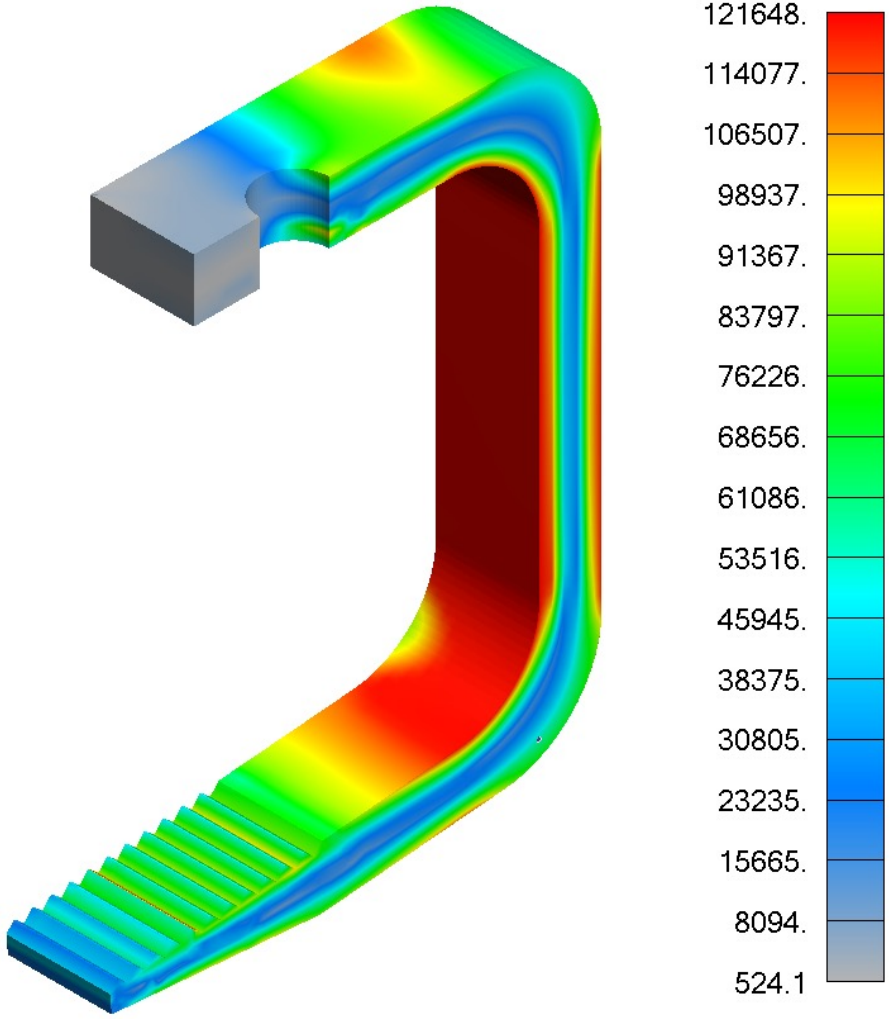
Fully structured hex meshes are notoriously difficult to generate, manually and with an algorithm.

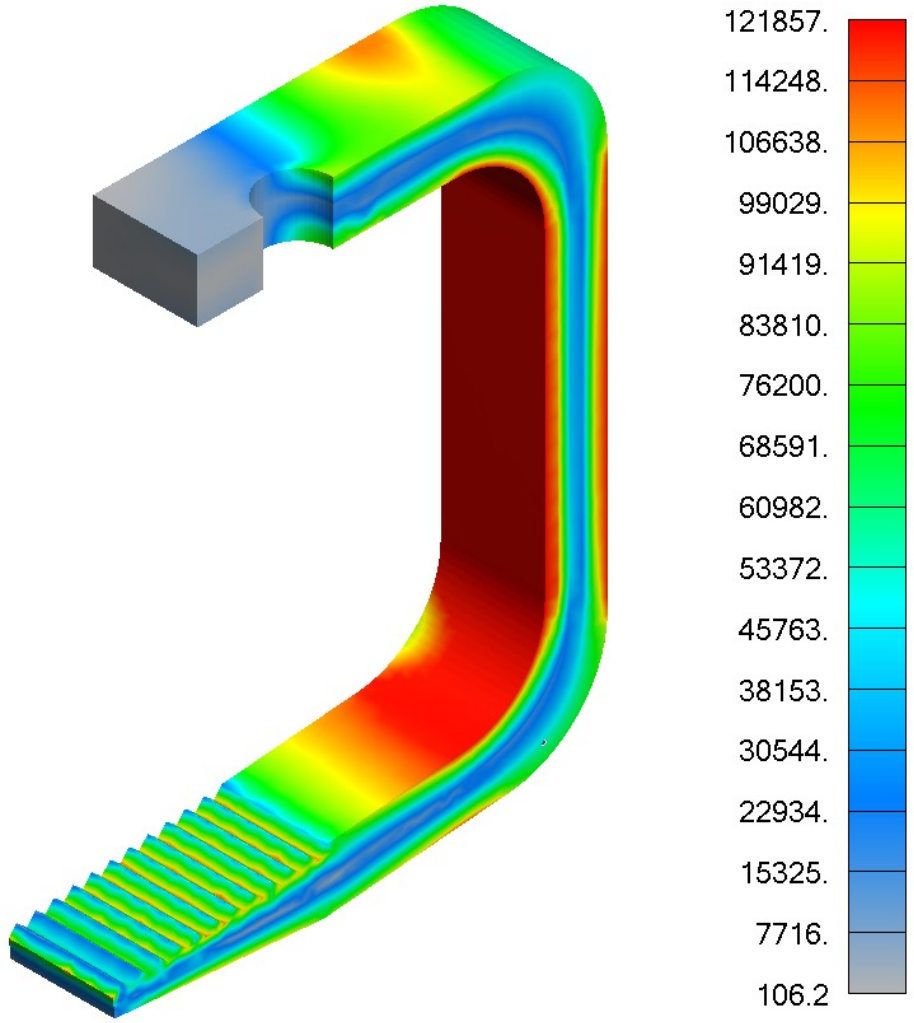
Automatic boundary conforming all-hex mesh generation has been dubbed the “holy grail” in the meshing community due to its desirability and difficulty to achieve.

Hex meshes are inflexible. Local modifications are difficult to implement and usually necessitate changes to the mesh in adjacent regions, which tends to cascade across an entire model.

This makes hex meshes ill-suited to mesh adaptation methodologies, as the containment of mesh refinement to specific regions is difficult.

So…. Why Use Hex Elements





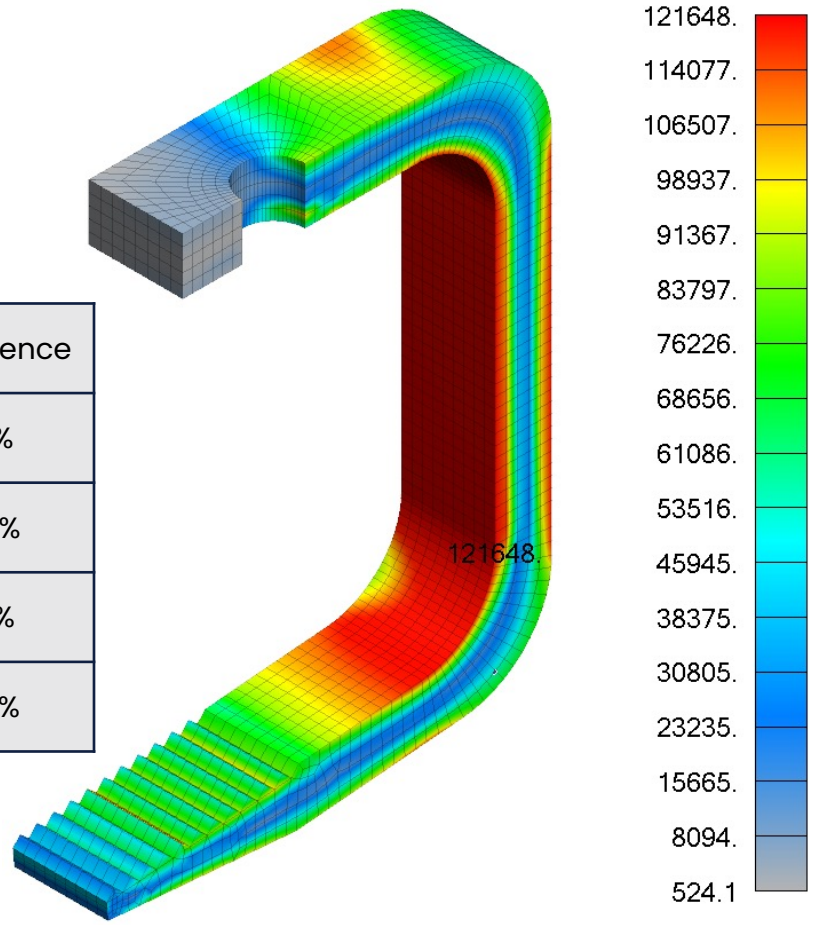
Why Use Hex Elements

AppliedCAx

SPEED!

Metric	Hexadederal Mesh	Tetrahederal Mesh	% Difference
Max von Mises Stress (psi)	121648	121857	0.2%
Run Time (seconds)	36	270	650%
Node Count	7844	56207	617%
Element Count	5778	36082	524%

Hex Meshed



Tet Meshed