... within Epsilon

Twin Cities
ANSYS® User Meeting

June 2018

Nonlinear Adaptivity

... within Epsilon

Agenda

1. Epsilon FEA Introduction
2. Nonlinear Adaptivity Overview
3. Nonlinear Adaptive Mesh Procedure
4. Nonlinear Adaptivity Case Studies
5. Q&A

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*** ERROR *** CP = 2872.649 TIME= 16:29:51
One or more elements have become highly distorted. Excessive
distortion of elements is usually a symptom indicating the need for
corrective action elsewhere. Try incrementing the load more slowly
(increase the number of substeps or decrease the time step size). You
may need to improve your mesh to obtain elements with better aspect
ratios. Also consider the behavior of materials, contact pairs,
and/or constraint equations. If this message appears in the first
iteration of first substep, be sure to perform element shape checking.
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... within Epsilon

Intro to Epsilon

- Epsilon FEA provides engineering analysis (10 yrs!)
- Making Simulation Accurate
  - In-depth knowledge of the tools
    - ANSYS® Suite of Multi-Physics software
  - Experience with industry successes/failures
    - Aerospace, Rotating Machinery, Electronics, Manufacturing, Packaging, etc.
  - We validate with calibration runs and hand-calcs
    - Experienced Assessing Discretization Error

- Making Simulation Affordable
  - Low hourly rates and/or fixed-price estimates
  - We use specialized experienced engineers
  - Detailed statements of work, scope and budget tracking
  - Automation (APDL, ACT, Journaling)

... within Epsilon

Epsilon’s Customers

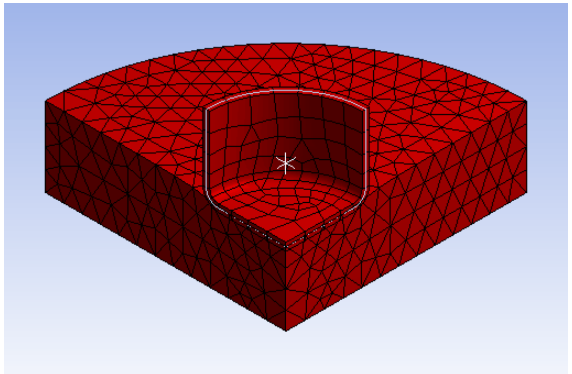
- Our customers need load-leveling with:
  - Analyst is a team-member, not a black-box
    - Interface with same Epsilon analyst to leverage past experiences
  - Open and frequent communication
  - Any new FEA methods/lessons learned are well communicated
  - Schedule/budget fidelity with frequent status updates
    - Achieved by using the right person, tools, and technical approach

Critical!

- Our customers benefit from external expertise
  - We infuse up-to-date FEA methods/tools
    - Leverage other industries’ FEA innovations
  - We are not a software reseller
    - Unbiased tool selection, infrastructure advice
  - We share our knowledge, files, and lessons learned!

Nonlinear Adaptive Region

- For large deflection analyses with high element distortion
- Reported to resolve convergence issues with high element distortions, esp. plasticity & elastomers
- Automated form of mesh rezoning
- A few adaptive mesh criteria exist
  - Will focus on mesh quality
- Limitations apply



Nonlinear Adaptivity

- Implemented during Solution options
  - Define subset of timesteps to check
    - less computation time
  - Multiple criteria options
    - mesh quality
    - strain energy
    - bounding box
  - Only remeshes when criteria is met and only remeshes in problem areas

Adaptive Mesh: Limitations

- Must use tetrahedral elements for 3D bodies
  - Can be linear (SOLID285s) or quadratic (SOLID187s)
  - Quadratic tet capability is new in V19
  - Quadratic elements recommended
- Scope to solid bodies or elements only (3D or 2D planar) – no shells
- Altered mesh cannot be shared between linked analyses
- May introduce solution chatter that would otherwise not be present
- Instabilities can cause convergence issues

Adaptive Mesh: Limitations

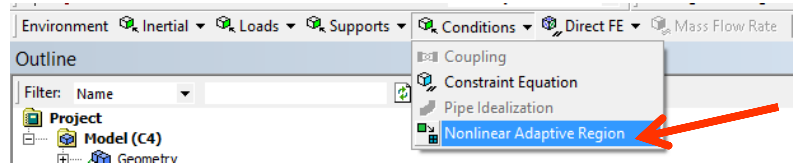
Cannot be used in combination with the following features/conditions on the same part:

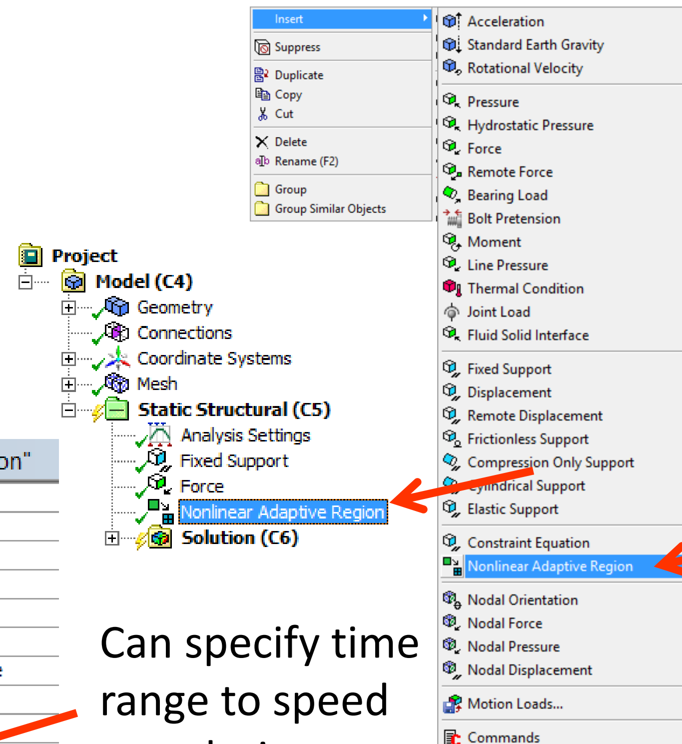
- Cyclic Symmetry
- Contact Formulations: Normal Lagrange (3D), MPC, and Beam
- Contact Behaviors: Auto Asymmetric
- Point Mass, Beam Connection, Joints, Spring, and Bearing
- Remote Force, Remote Displacement, Moment, Thermal Condition, and Remote Point
- Spatially varying boundary conditions
- Coupling
- Constraint Equation

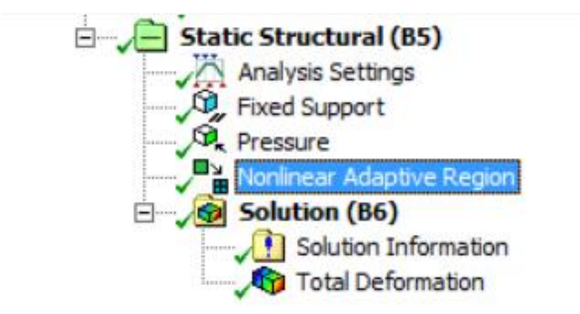
Same limitations as in R16.

Adaptive Meshing: Procedure

- With environment selected in the tree, insert Nonlinear Adaptive Region or select it from the Conditions toolbar
- Can only be scoped to a body or named selection of elements
- Select criterion and time range to check upon







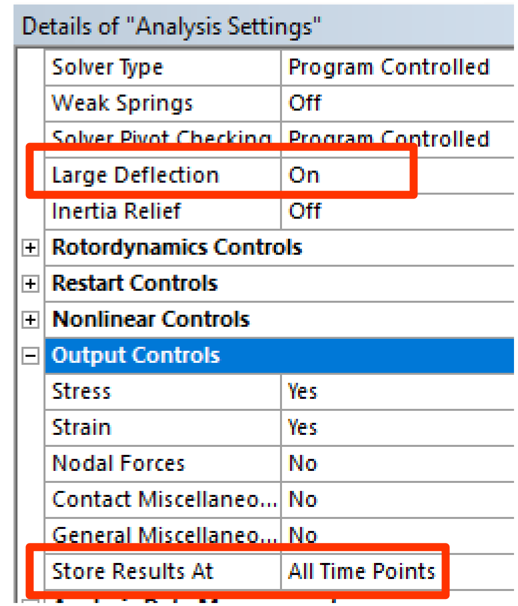
Details of "Nonlinear Adaptive Region"

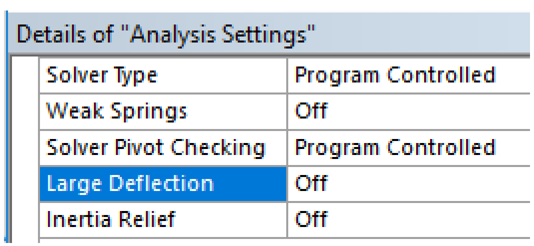
Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Criterion	Skewness
Skewness Value	0.85
Check At	Specified Recurrence Rate
--- Value	1
Time Range	Entire Load Step
Suppressed	No

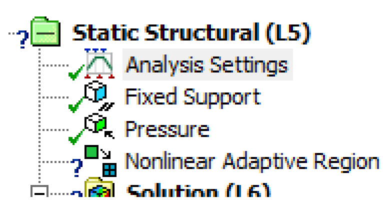
Can specify time range to speed up solution

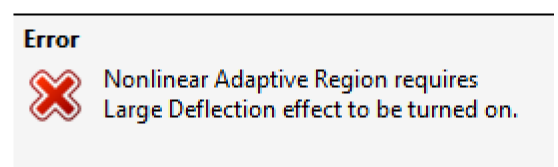
Adaptive Meshing: Procedure

- Required Analysis Settings:
  - Large Deflection = On
  - Store Results = All Time Points
  - Note: If Large Deflection = Off or Store Results ≠ All Time Points, a ? will appear next to the Nonlinear Adaptive Region object, and it will not be obvious as to why.
  - Click the Show Errors Button to troubleshoot ?✓ Show Errors



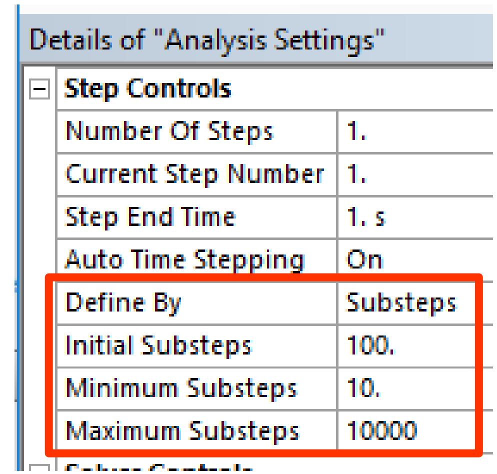






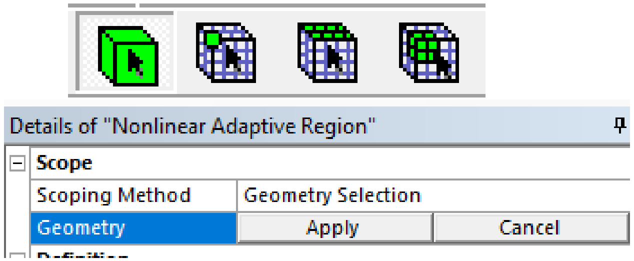
Adaptive Meshing: Procedure

- Auto Time Stepping
  - Default Auto Time Step settings are often adequate for material nonlinearities without nonlinear adaptivity
  - For nonlinear adaptivity, auto time stepping should be manually specified to obtain desired adaptivity
  - Be generous with number of time steps
    - Some test cases would succeed with the relatively large default 1st step, but encounter problems later



Adaptive Meshing: Procedure

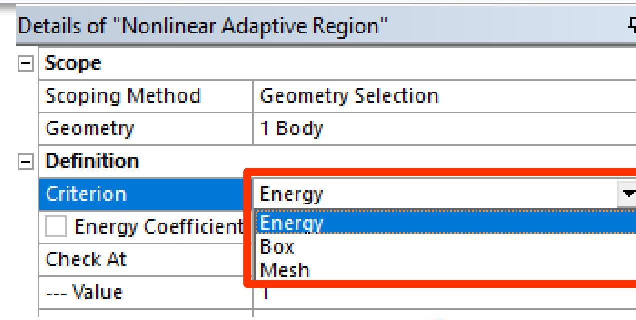
- Scoping: Geometry or Named Selection
  - When Scoping Method is set to Geometry, Body, Node, Element Face, and Element selection filters are available. Body filter is the only valid one.
  - Must create a Named Selection from elements to scope to elements

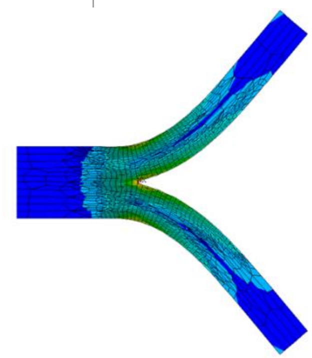


- Mechanical will allow scoping to a Hex-Meshed Body
  - No mesh adaptivity will occur

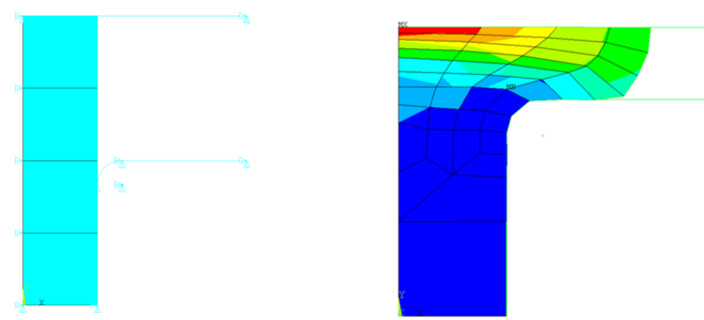
Adaptive Meshing: Procedure

- Criterion = Energy, Box, or Mesh
  - Energy is used to improve accuracy of crack growth modeling based on strain energy
  - Box dictates the location of elements to be split after deformation.
    - Uses coordinate locations on any elements entering the region.
    - Typically used to model seating of a seal undergoing high deformation
  - Mesh monitors mesh quality throughout load event and remeshes when elements become overly distorted.
  - We will focus on Mesh criterion herein





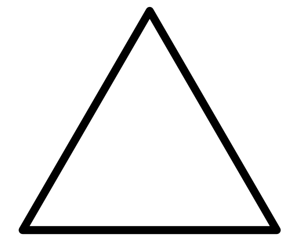
Energy Criterion



Box Criterion

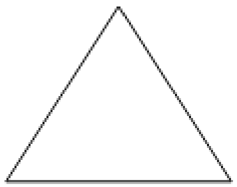
Adaptive Meshing: Procedure

- Mesh Criterion Options
  - Skewness
    - Reflects “flatness” of element
    - Valid for linear and quadratic elements
    - 0 is perfectly shape; 1 is completely flat
    - Default Skewness Value = 0.9; recommended skewness = 0.9 - 0.95
  - Jacobian Ratio
    - Reflects if element is turning inside-out
    - Valid for quadratic elements only
    - 1 is ideal; 0 is threshold; < 0 is inside-out
    - Default Jacobian = 0.1; recommend Jacobian = 0.01 – 0.15
  - Note that Skewness and Jacobian are normalized values in ANSYS

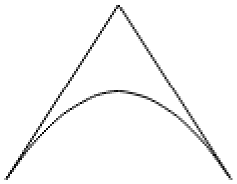


Skewness = 0

Skewness approaching 1



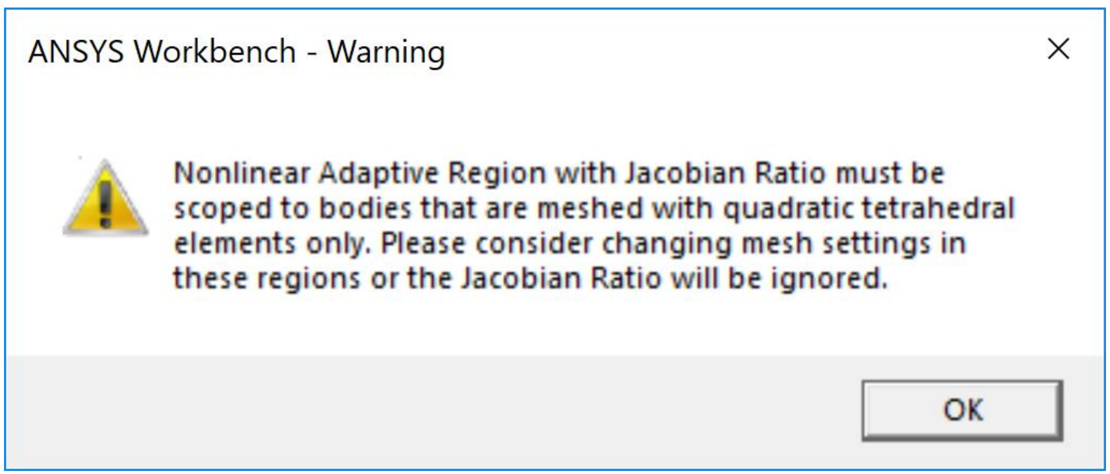
Jacobian = 1

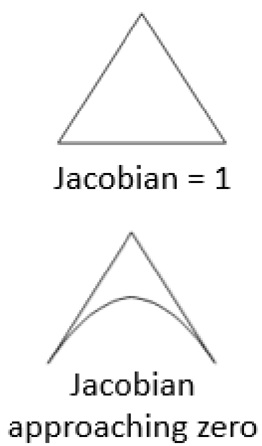


Jacobian approaching zero

Jacobian Ratio Warning

- Jacobian ratio criterion applies to quadratic elements only
  - Only skewness criterion applies to linear elements, Jacobian ignored
  - Warning message will display regardless of scope





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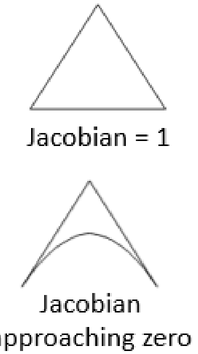
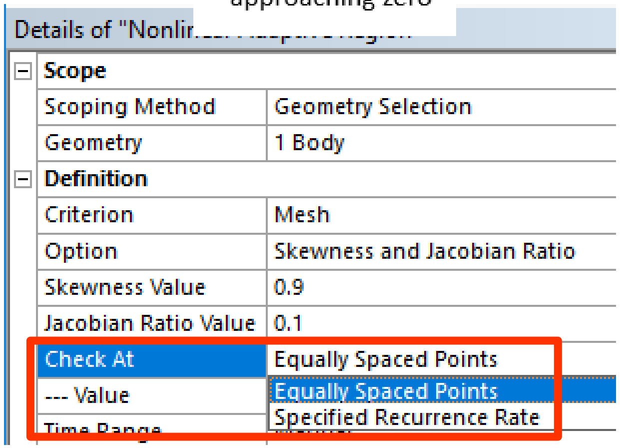
Adaptive Meshing: Procedure

- Mesh Check Frequency
  - Check At = Equally Spaced Points (default)
    - Checks mesh quality for rezoning need at *Value* time points between Start and End Time
  - Specified Recurrence Rate
    - Checks mesh quality at ever step
    - Recommended



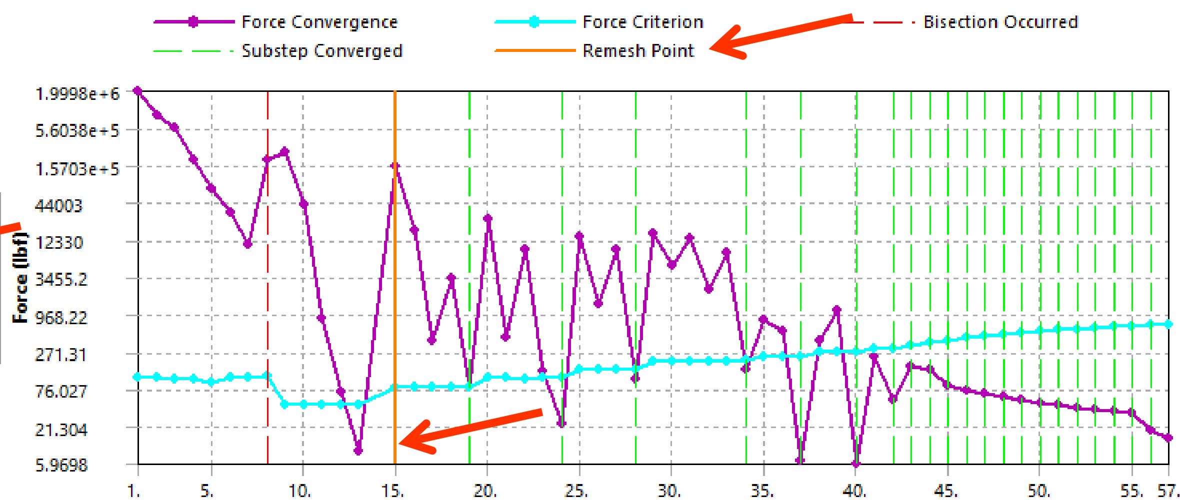

Details of "Nonlir…

Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Criterion	Mesh
Option	Skewness and Jacobian Ratio
Skewness Value	0.9
Jacobian Ratio Value	0.1
Check At	Equally Spaced Points
--- Value	Equally Spaced Points
Time Range	Specified Recurrence Rate

Adaptive Meshing: Results

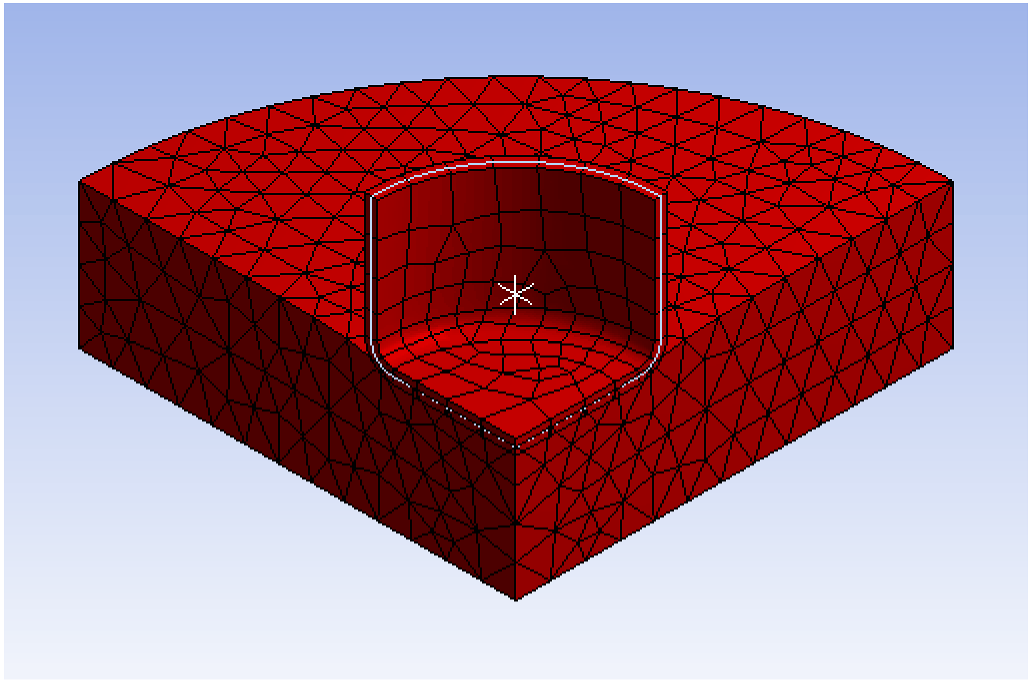
Check force/displacement convergence graphs or tabular data to find which time step/substep a remesh was applied

	Time [s]	Minimum [in]	Maximum [in]	Changed Mesh
1	2.e-002	0.	1.0131	
2	4.e-002	0.	1.731	Yes
3	6.e-002	0.	2.1757	
4	9.e-002	0.	2.6325	
5	0.135	0.	2.9689	



Adaptive Meshing: Results

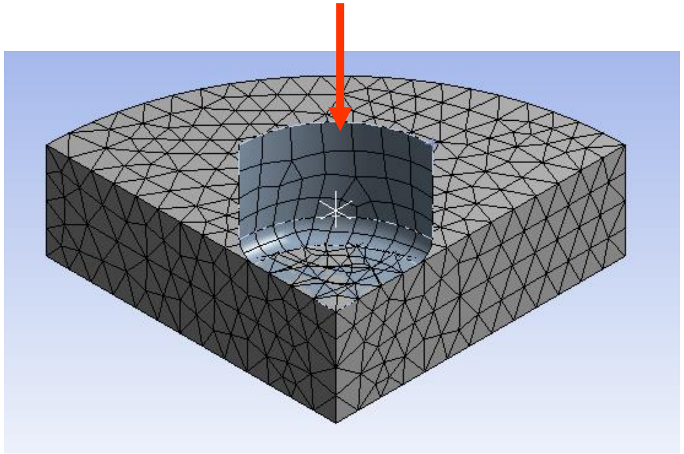
Compare pre-mesh change and post-mesh change substeps to find regions of improvement



Case Study 1a: Metal Forming

- 1" thick, 3" radius disk is crushed in the center by a 1" radius forming tool. (1/4 symmetry model)
- Element size = Default (0.23)
- 301 ¼ hard bilinear isometric material model
- Compare linear and quadratic models, with and without nonlinear adaptive regions

Determine amount of crush before convergence failure

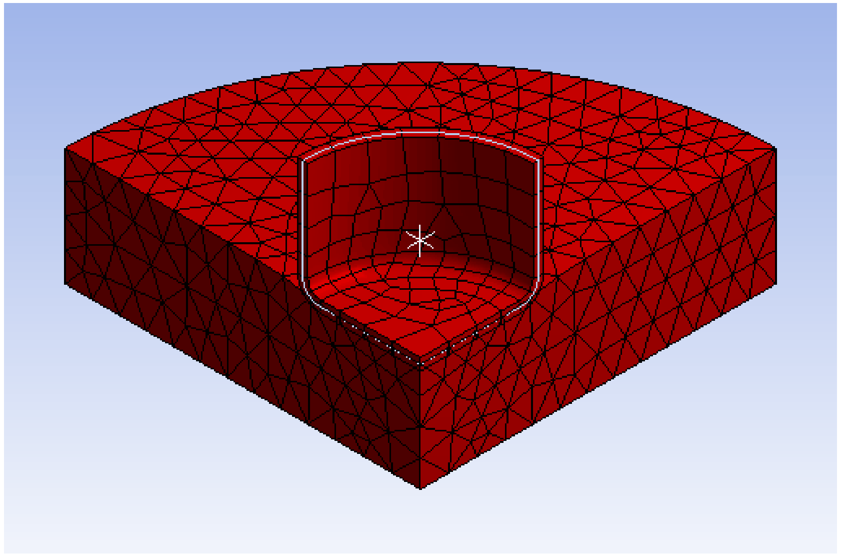


Case Study 1a: Metal Forming

- Metal forming summary of findings
  - Note stress results were similar, even with poorly shaped elements for no NLAD

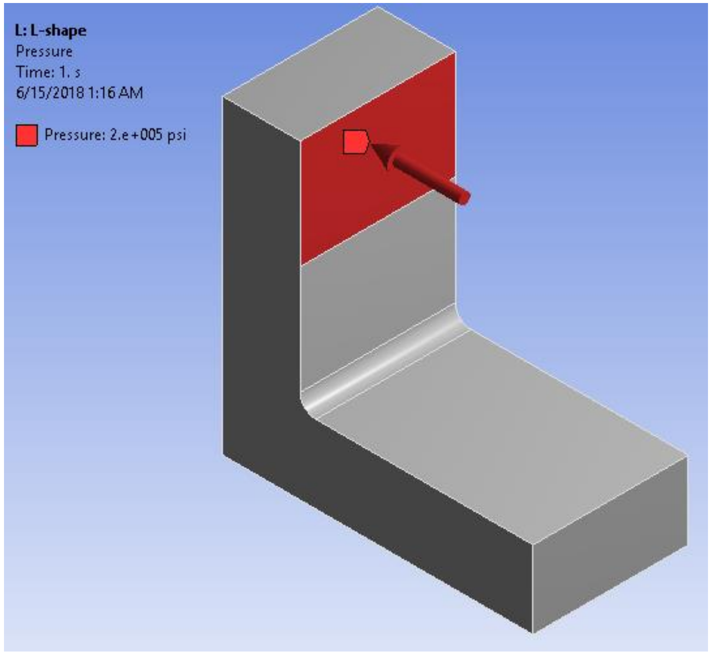
Element Order	Adaptivity?	Max Deflection	Elapsed Time	Remeshes
Linear	No	0.52"	1 m 29 s	N/A
Linear	Yes	0.8"	3 m 16 s	12
Quadratic	No	0.82"	2 m 31 s	N/A
Quadratic	Yes	0.86"	4 m 59 s	11

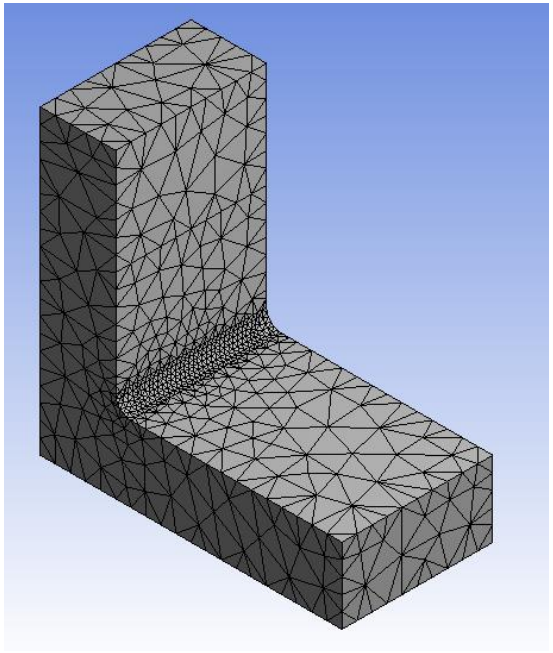
Consider activating only if required!



Case Study 1b: Linear vs Quadratic

- L-shaped bracket
- 200,000 psi applied to top flange
- Fixed at bottom
- Compare results for linear and quadratic elements





Case Study 1b: Linear vs Quadratic

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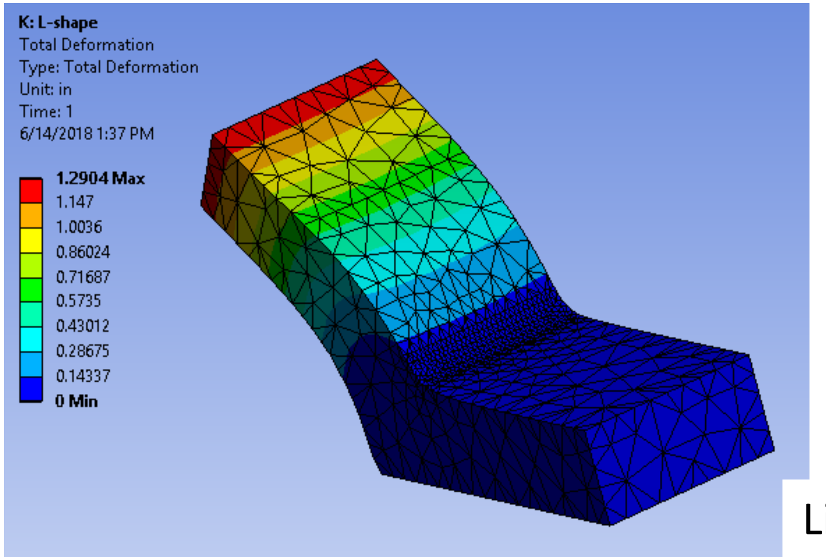
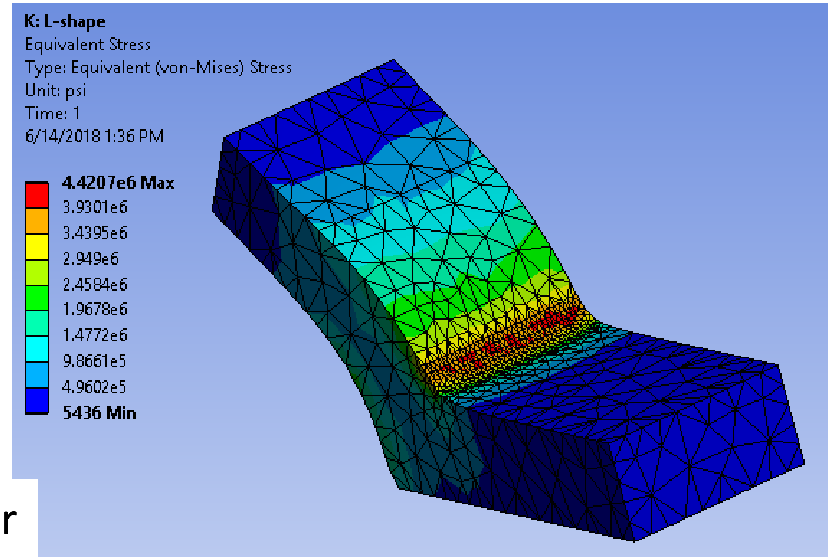
Linear vs Quadratic Element Results

Element Order	Max Deflection	Max Stress
Linear	1.29"	4420000 psi
Quadratic	1.51"	4830000 psi

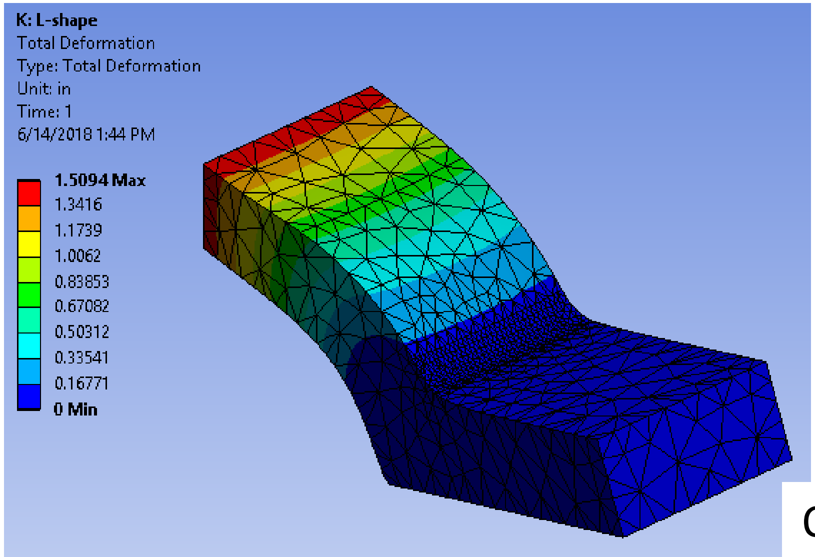
- Even with mixed U-P formulation, 4-noded elements are too stiff.
  - Before NLAD, mixed U-P formulation was our best tool (besides smaller time steps).
- Use quadratic elements with nonlinear adaptivity now that the option is available.

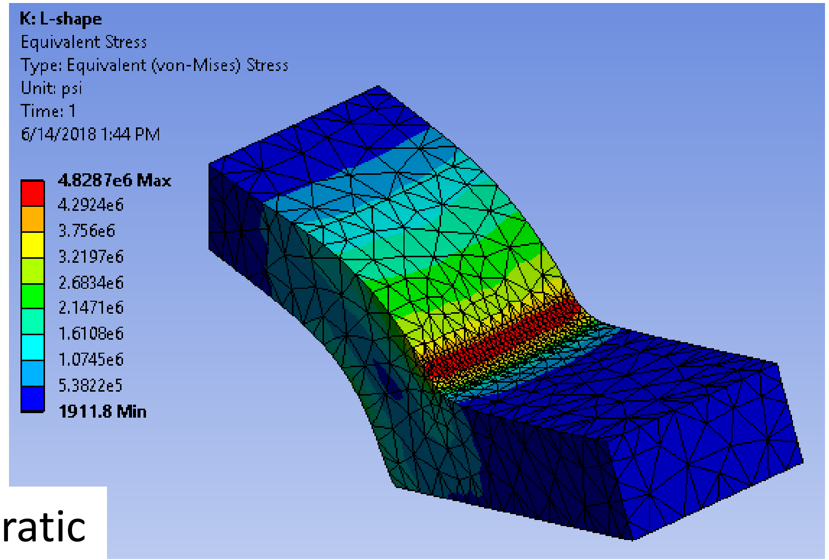
Case Study 1b: Linear vs Quadratic





Linear

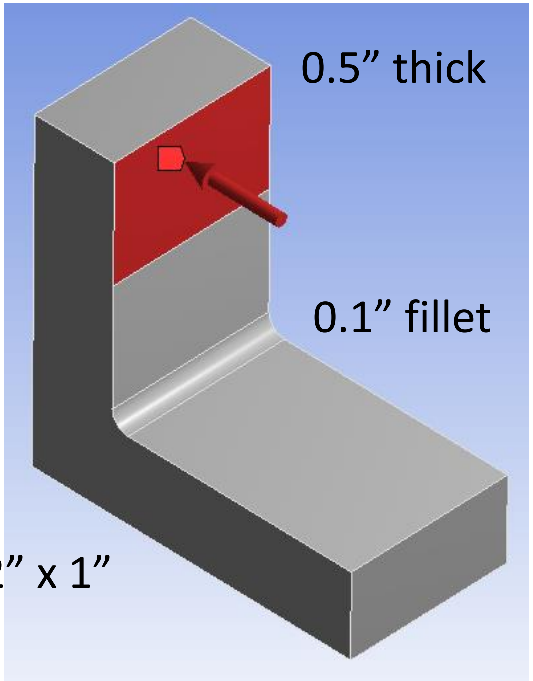


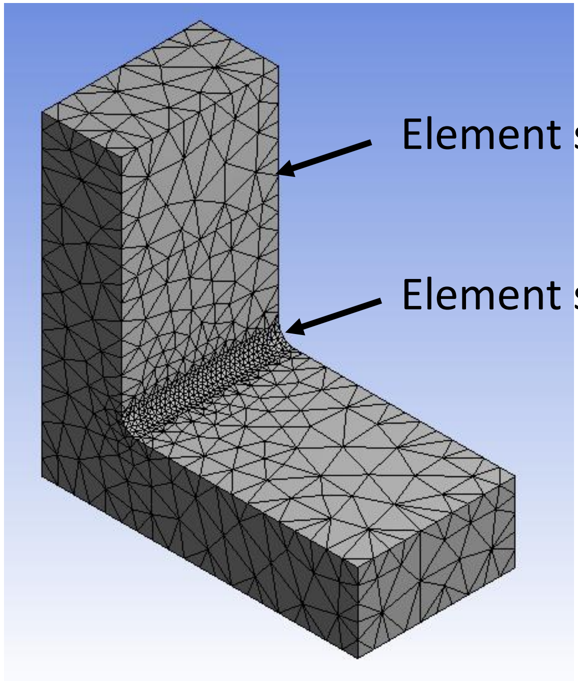


Quadratic

Case Study 2a: L-Bracket

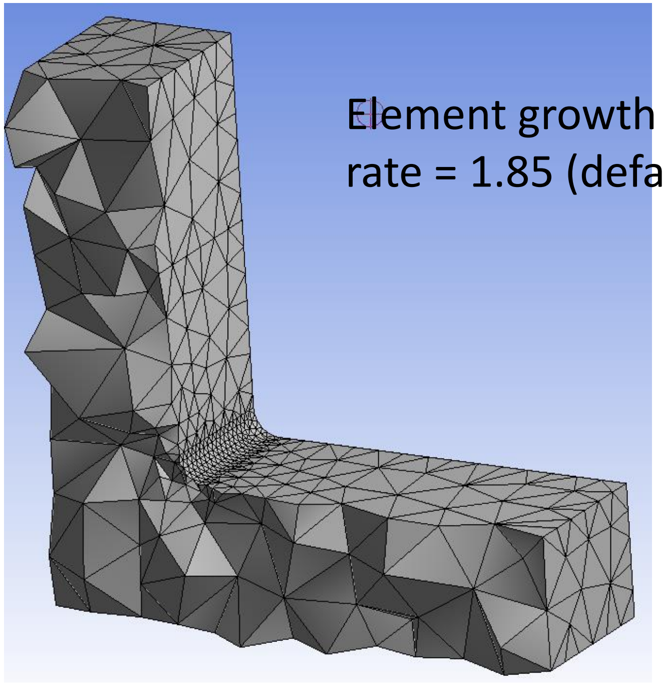
- L-shaped bracket: 301 ¼ hard, BISO plasticity
- Pressure applied to top flange
- Fixed at bottom
- Determine maximum pressure model will converge at with and without the nonlinear adaptive region

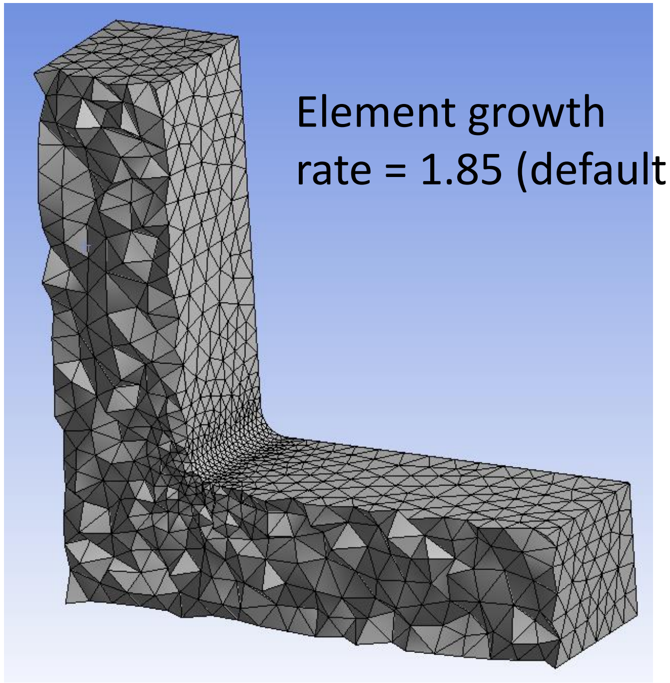




Case Study 2a: L-Bracket

- Study effect of improving mesh quality by reducing element growth rate from fine to coarse vs using a nonlinear adaptive region.



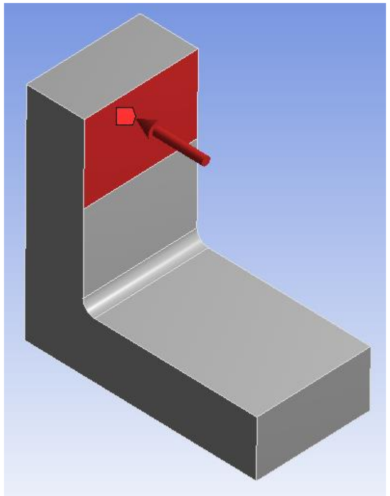


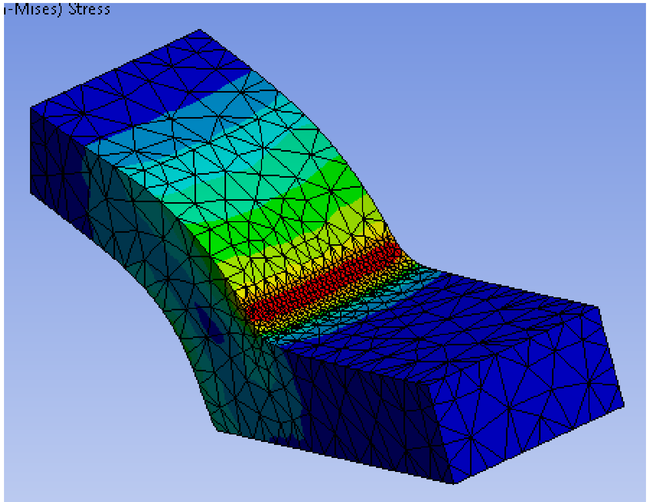
Case Study 2a: L-Bracket

L-Bracket maximum pressure results

Adaptivity?	Growth Rate	Max Pressure	Elapsed Time	Max Strain	Number Remeshes
No	1.85	1.4 GPa	2.8 min	50%	N/A
No	1.20	2.1 GPa	18.0 min	63%	N/A
Yes	1.85	3.4 GPa	35.7 min	78%	32

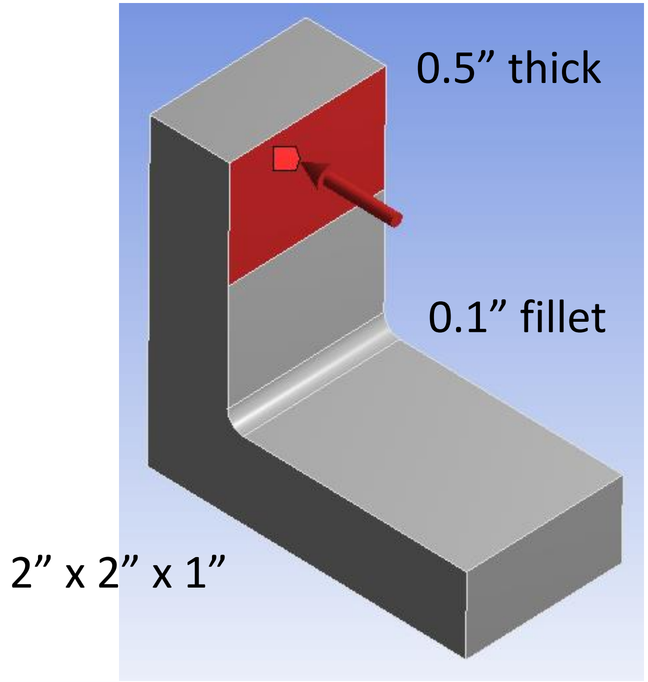
Adjusting growth rate improved convergence behavior, but not as much as nonlinear adaptivity. Both approaches introduce significant time cost.

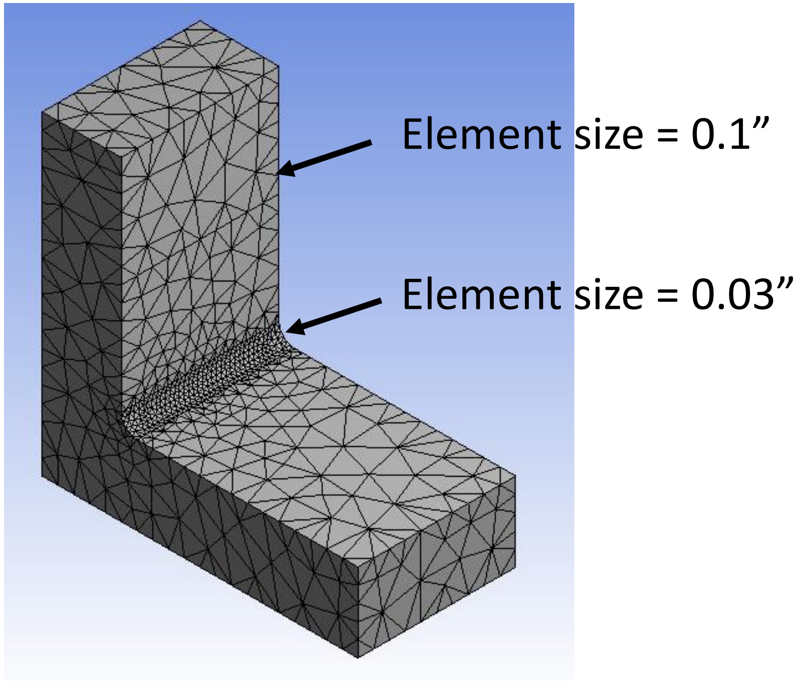




Case Study 2b: L-Bracket

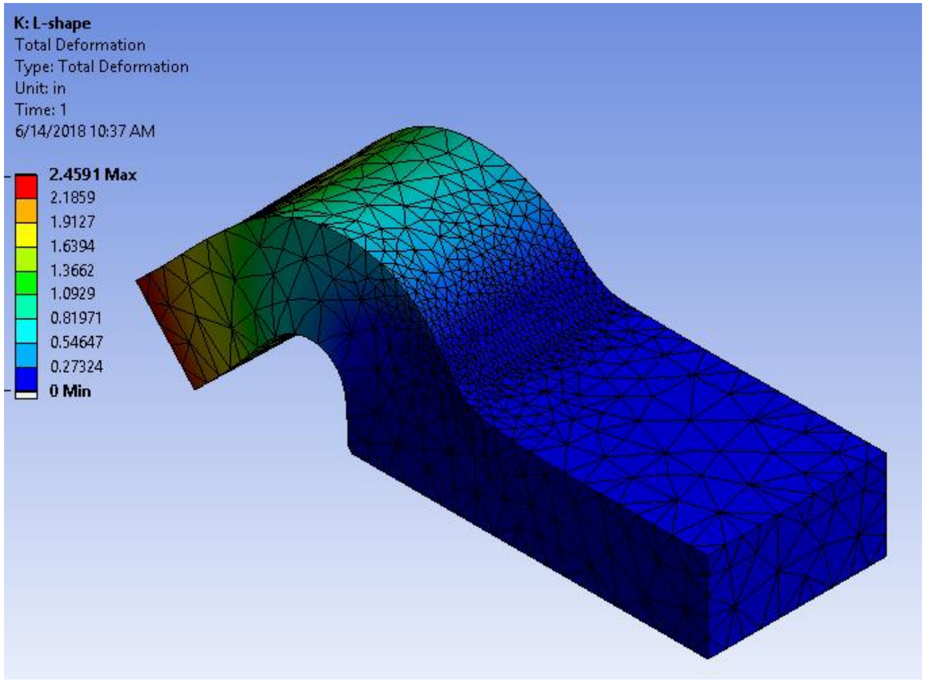
- L-shaped bracket: 301 ¼ hard, BISO plasticity
- 400,000 pressure applied to top flange
- Fixed at bottom
- Determine effect of various settings on solve performance

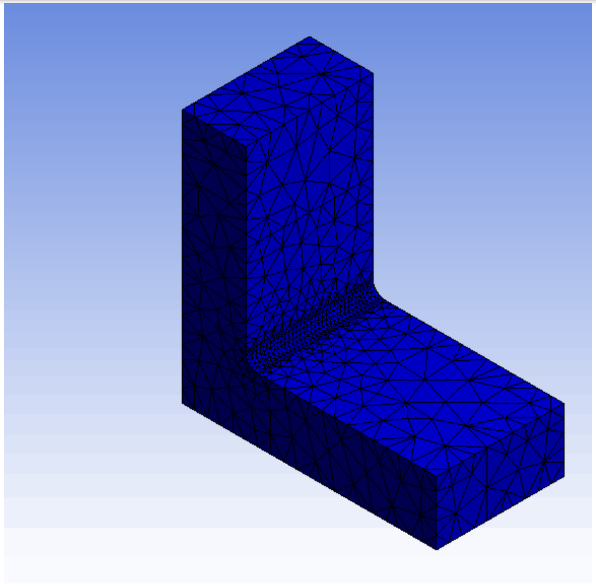


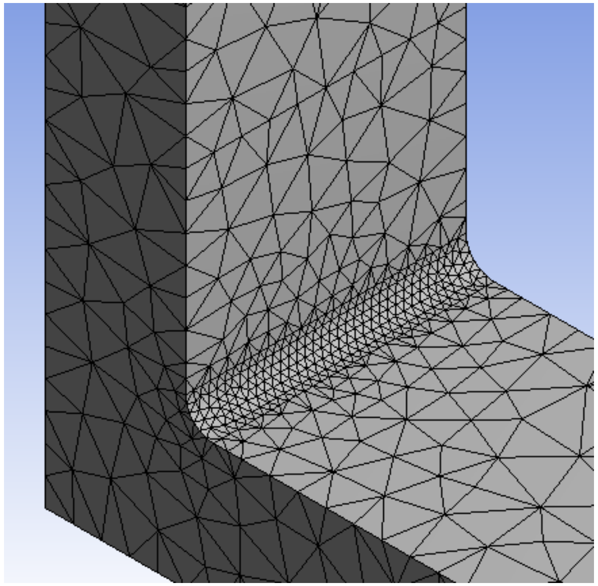


Case Study 2b: L-Bracket

L-bracket nonlinear adaptive results animations







Case Study 2b: L-Bracket

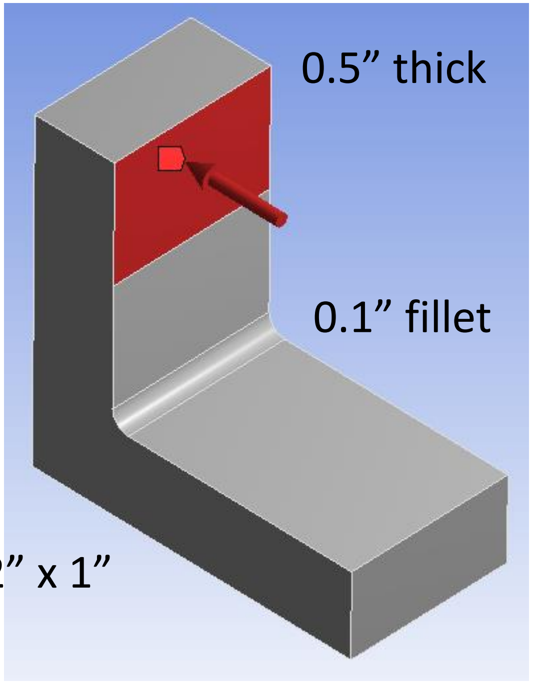
L-bracket solve performance results

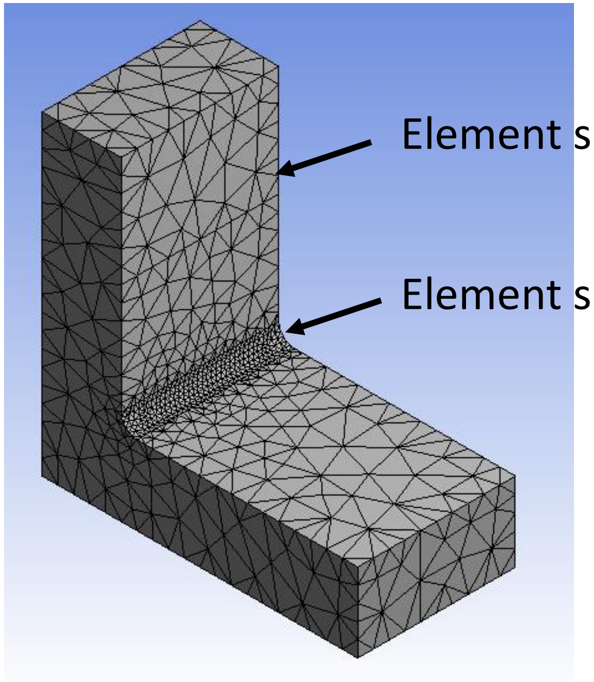
Recurrence Rate	Scoping	Elapsed Time	Remeshes
1	Entire Body	6 m 53 s	22
2	Entire Body	10 m 10 s	22
5	Entire Body	9 m 6 s	10
1	X, Y = 0 - 1"	15 m 12 s	20

- Best performance was with Recurrence Rate = 1 and Nonlinear Adaptive Region scoped to entire body.
- This is consistent with our other case studies.

Case Study 2c: L-Bracket MISO

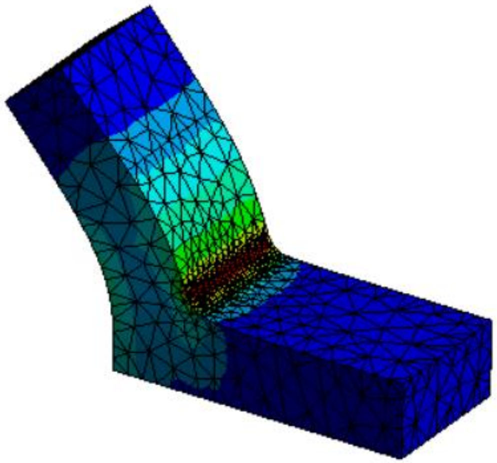
- L-shaped bracket: 301 ¼ hard, MISO plasticity
- 400,000 pressure applied to top flange
- Fixed at bottom
- Determine effect of various settings on solve performance

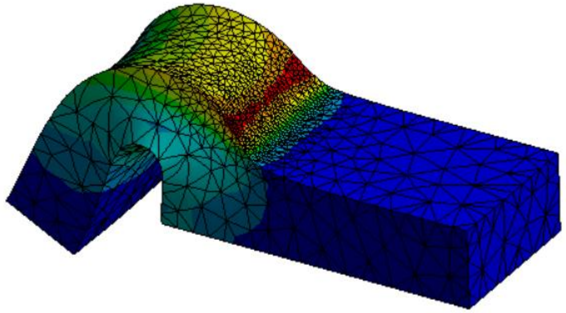




Case Study 2c: L-Bracket, MISO

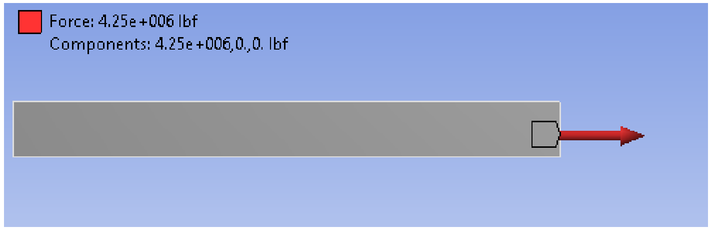
- Without NLAD, fails at 34% strain
  - Initial step size was not a factor
- Adding NLAD, fails at 82% strain
  - Initial step size was not a factor

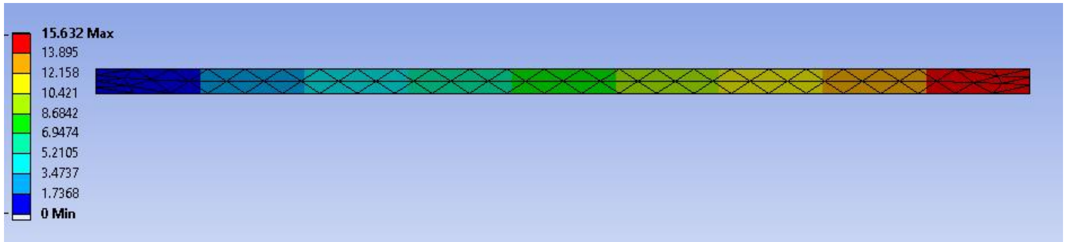


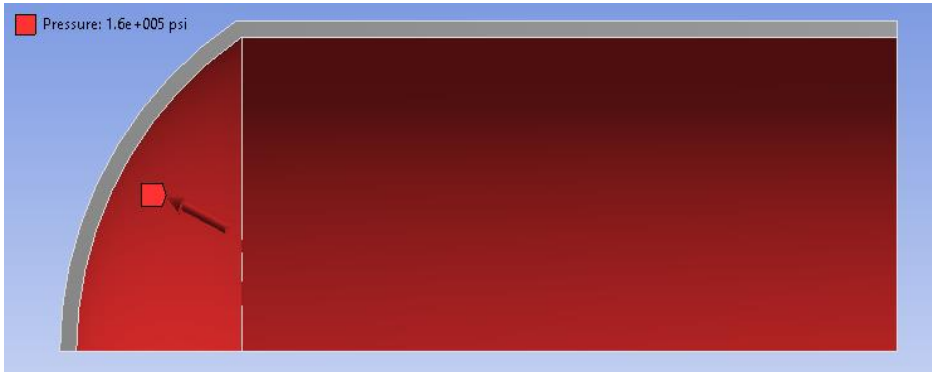


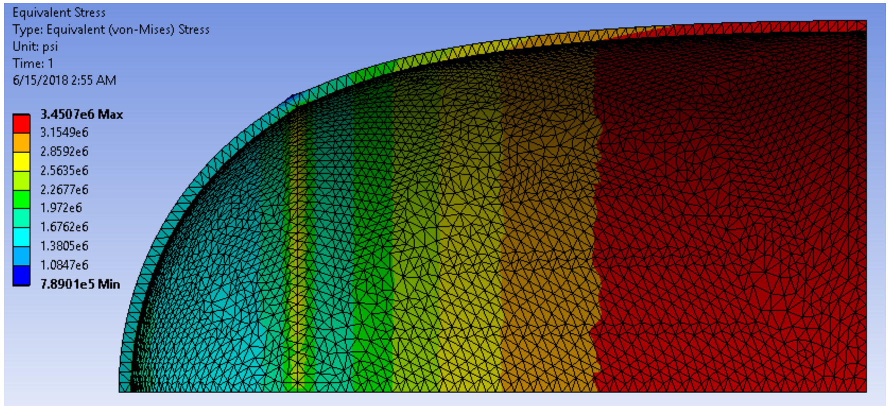
Case Study 3: Membrane Loads

- Studies were performed on three cases in which loading was primarily in the membrane or axial direction
  - Axially loaded beam
  - Pressure vessel
  - Pulling of a cylindrical boss attached to a cylinder



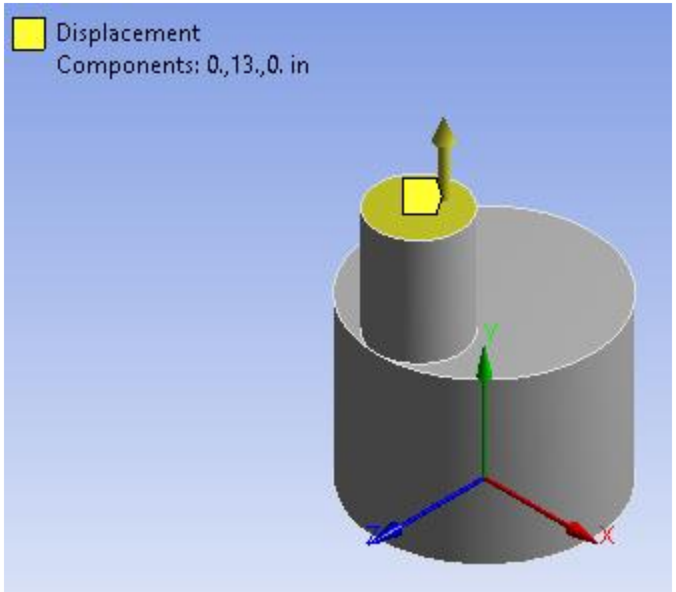


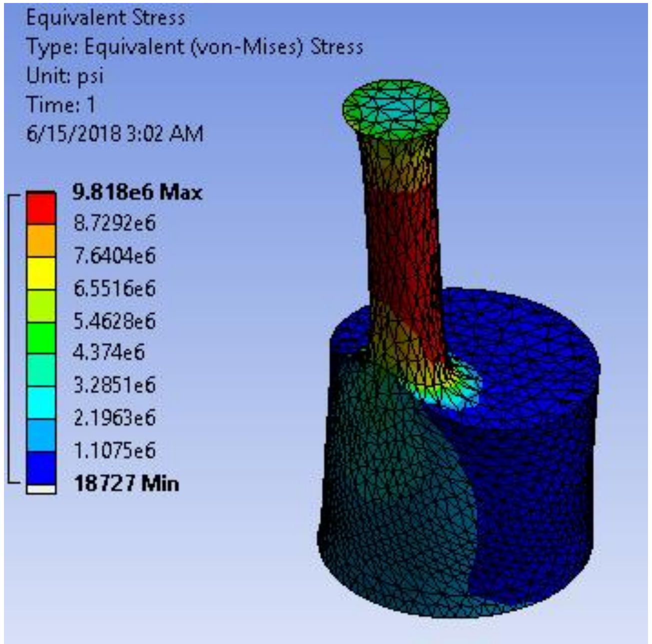




Case Study 3: Membrane Loads

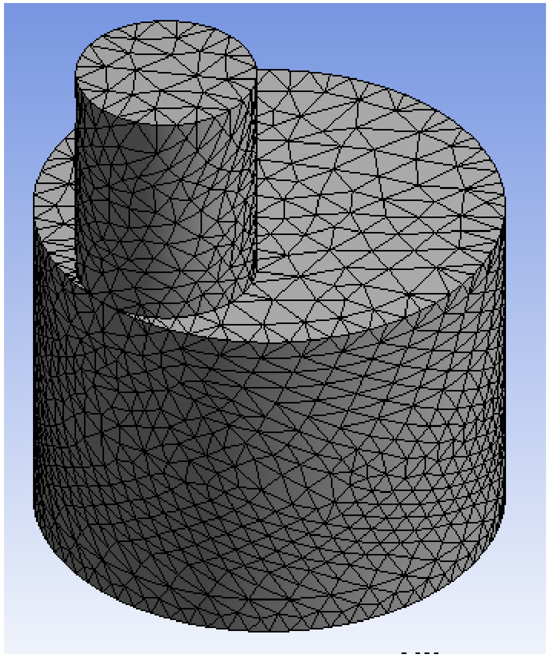
- In no case did nonlinear adaptivity significantly improve converge behavior; perhaps by a small amount, but with a drastic time cost
- Convergence failure in each case appeared to be due to unstable materials rather than excessive element distortion

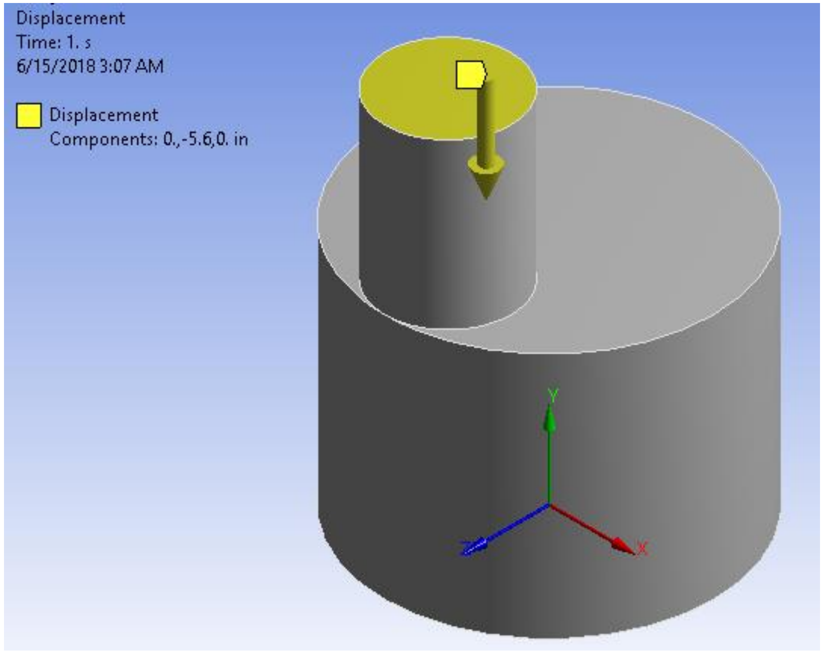




Case Study 4: Slivers

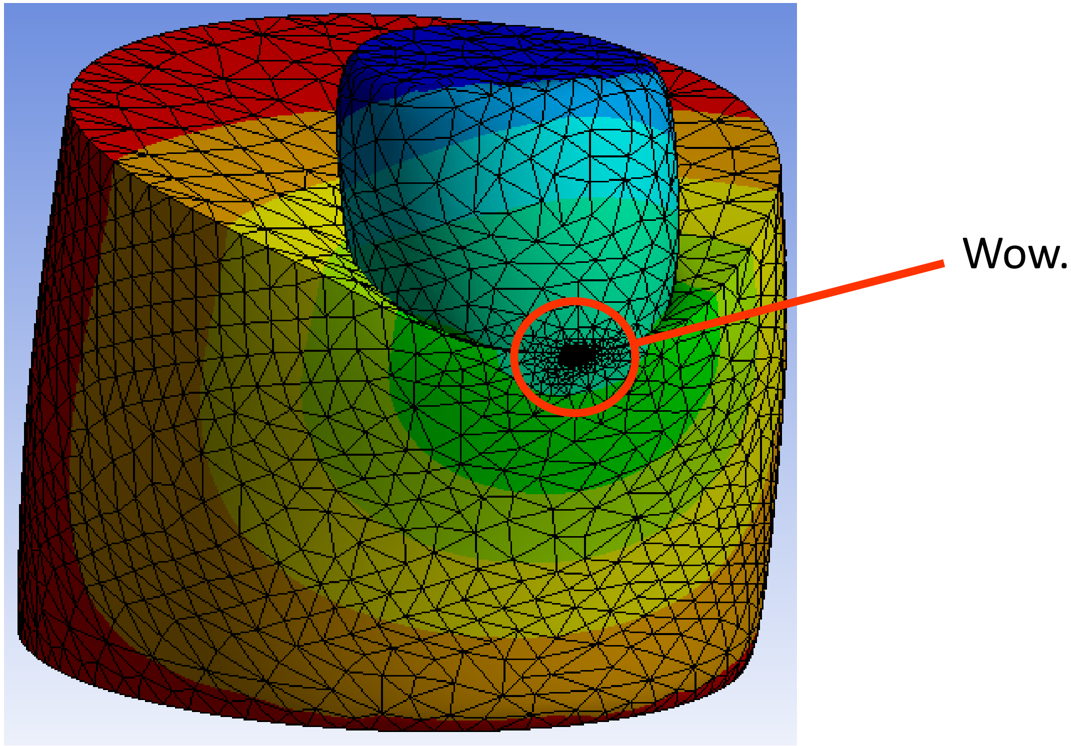
- What happens when a nonlinear adaptive region includes slivers, such as two cylindrical components tangent to one another
- What corrective actions can be taken?





Case Study 4: Slivers

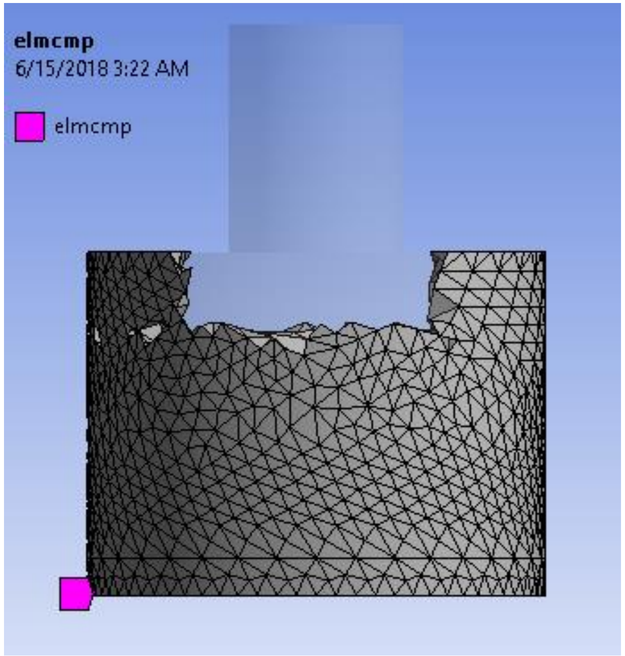
- Nonlinear adaptivity scoped to whole body, recurrence rate = 1

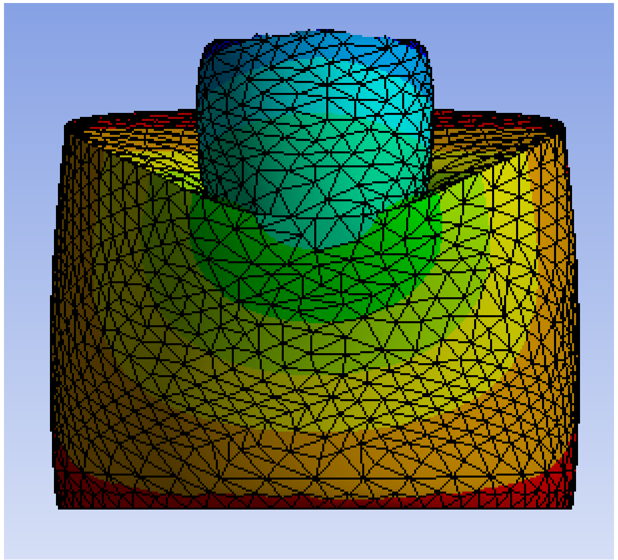


Adaptive rezoning is occurring in a region where satisfactory element shape quality is impossible due to the sliver regions

Case Study 4: Slivers

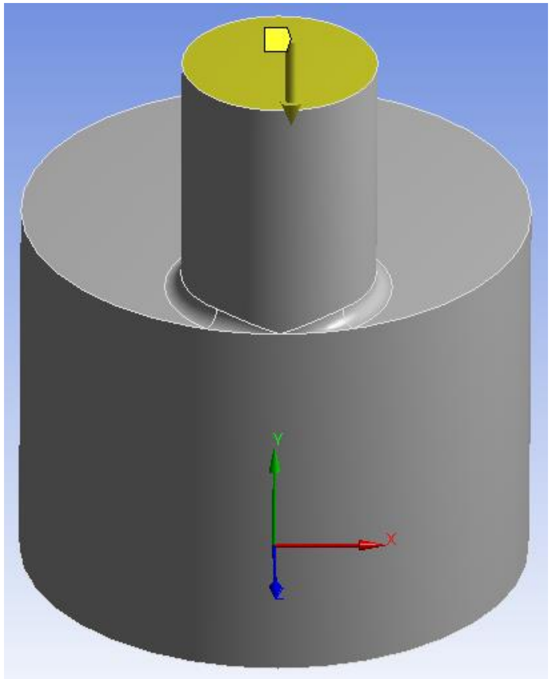
- Possible correction: Scope adaptivity to Named Selection of elements away from sliver region.

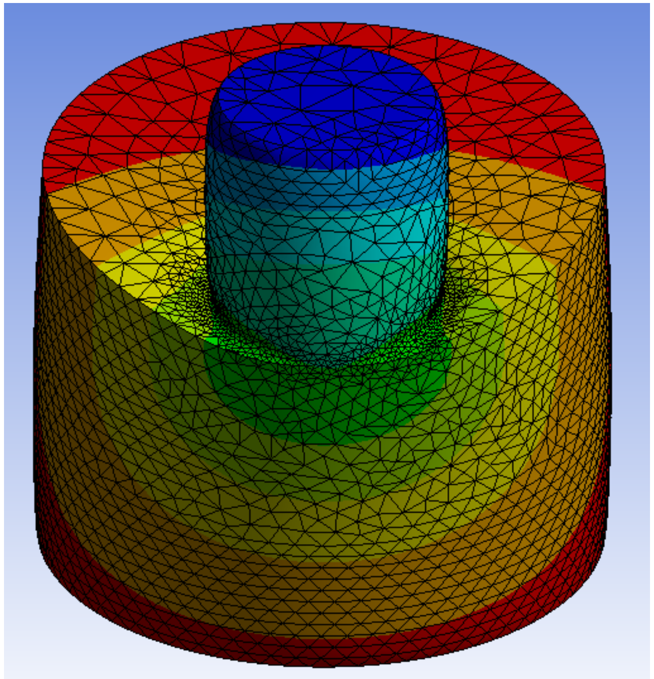




Case Study 4: Slivers

- Possible correction: Add fillets or blend the sliver out using other repair methods.

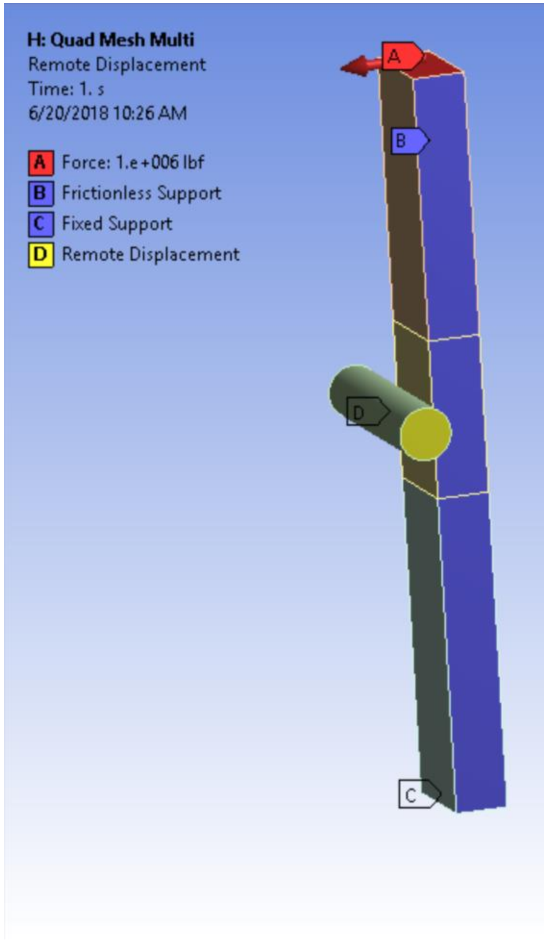




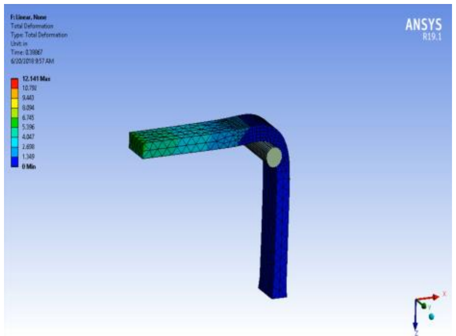
Note: This method did not converge nearly as well for this test case as scoping the Nonlinear Adaptive Region to a Named Selection did.

Case Study 5: Contact & Elongation

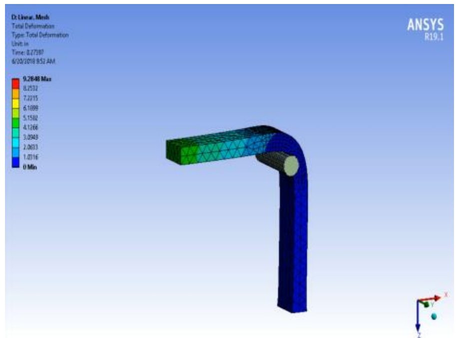
- Bending SS304 bar over rigid pin using frictionless Augmented LaGrange contact
- Both bilinear and multilinear plasticity tested
- NL Adaptive region criteria set to default values
  - Skewness of 0.9, Jacobian of 0.1
  - Energy coefficient of 1
- Check for remesh at all converged substeps



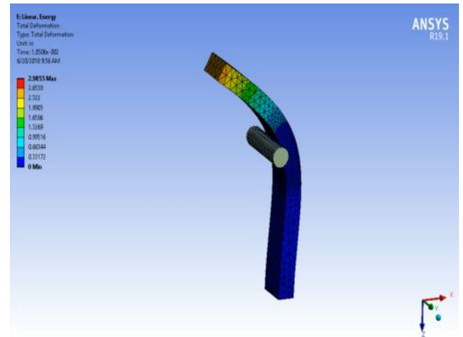
Case Study 5: Deformations



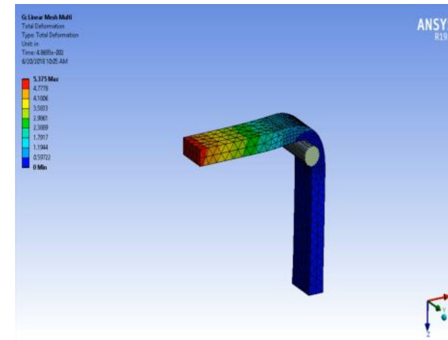
Linear Elements
No Remeshing



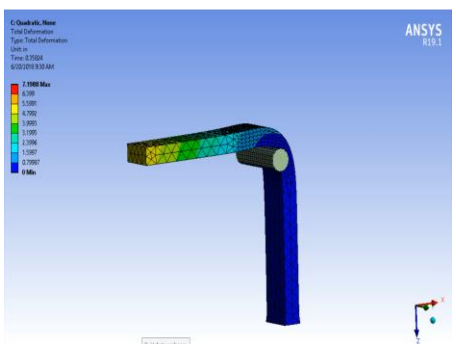
Linear Elements
Mesh Criterion



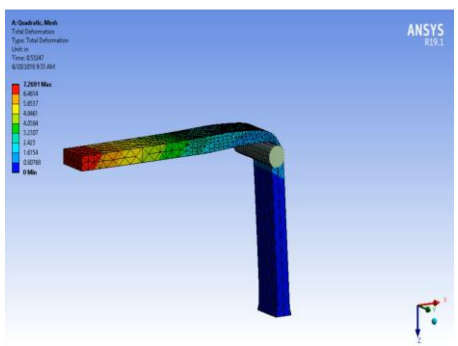
Linear Elements
Energy Criterion



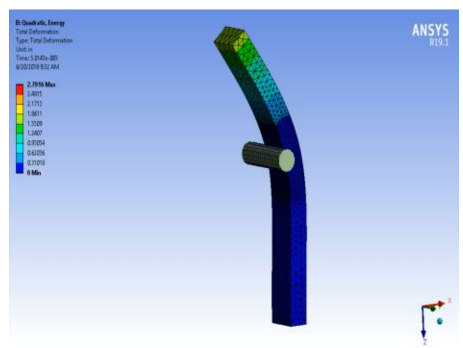
Linear Elements
Multilinear



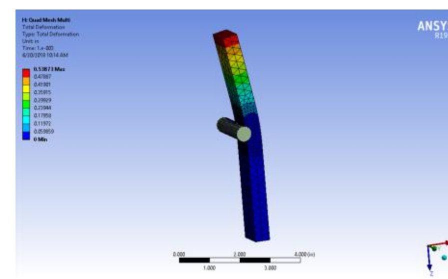
Quad Elements
No Remeshing



Quad Elements
Mesh Criterion



Quad Elements
Energy Criterion



Quad Elements
Multilinear

Case Study 5: Results

Element Type	Material Property	Remesh Criterion	No. of Remeshes	Max % Plastic Strain
Linear	Bilinear	None	0	88.4%
Linear	Bilinear	Mesh	19	99.7%
Linear	Bilinear	Energy	2	14.2%
Linear	Multilinear	Mesh	8	80%
Quadratic	Bilinear	None	0	103%
Quadratic	Bilinear	Mesh	20	137%
Quadratic	Bilinear	Energy*	4	12.8%
Quadratic	Multilinear	Mesh	0	4.6%
Quadratic	Multilinear	Mesh	10	109%
Quadratic	Multilinear	None	0	141%
Quadratic	Neohookean	Mesh	19	68%
Quadratic	Neohookean	None	0	69%

Small stepsize

*Solve ended due to extremely large element count using all hard disk space. Recommend a non-default setting specific to your application.

Conclusions

1. NLAD well addresses the element distortion errors
2. NLAD typically require more time to solve, but can be faster and more robust than trying to adjust the mesh.
3. A recurrence rate of 1 has shown to be an optimal mesh check rate in these test cases, (note the ANSYS recommending a recurrence rate of 2) – your mileage may vary.
4. Manual specification of auto time stepping values is strongly recommended and necessary in most cases.
5. NLAD performs better on distortion due to compression or bending than stretching

Conclusions

6. Fine tuning of criteria and load stepping usually required
   - Especially with energy criterion
7. Scoping the Nonlinear Adaptive Region to a named selection did not decrease the solution time,
   - Yet useful for avoiding regions in which the mesh will inherently be poorly shaped.
8. Adaptive regions have less of an effect on, and are less necessary for, quadratic elements than linear elements
   - Yet very useful for models with extreme material and geometric nonlinearities.
9. Slivers are still problematic.
10. NLAD well addresses element distortion errors.

Repeats item 1, but let's end on a high note!

Input / Questions