ANSYS

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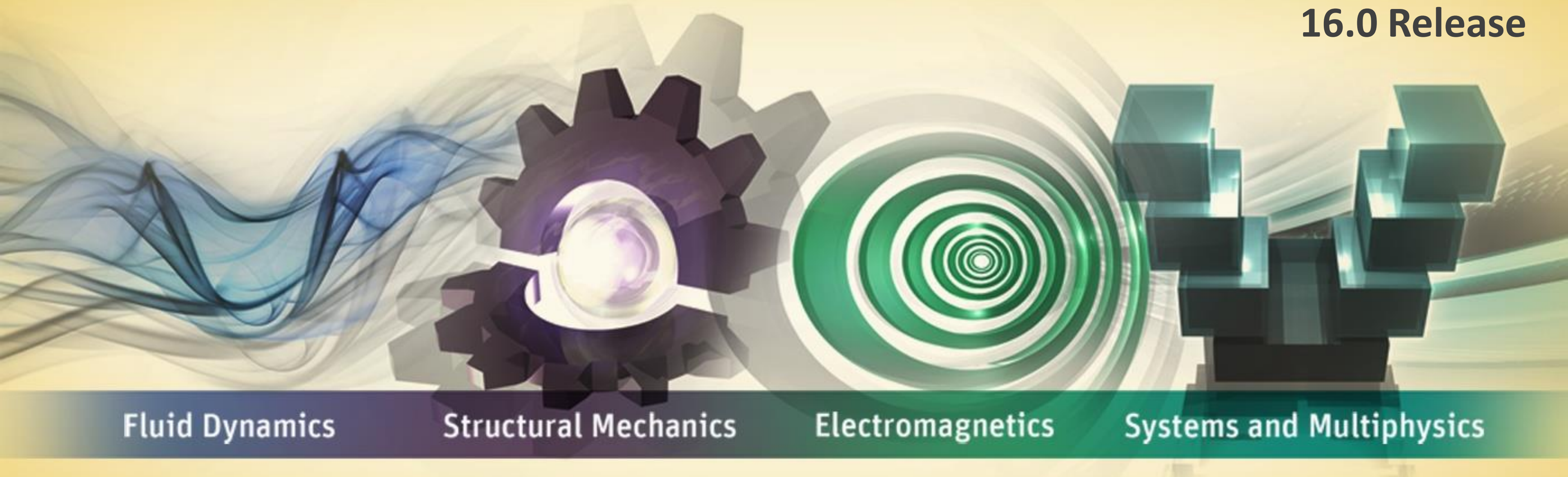
Workshop 4A:
Metal Plasticity

16.0 Release

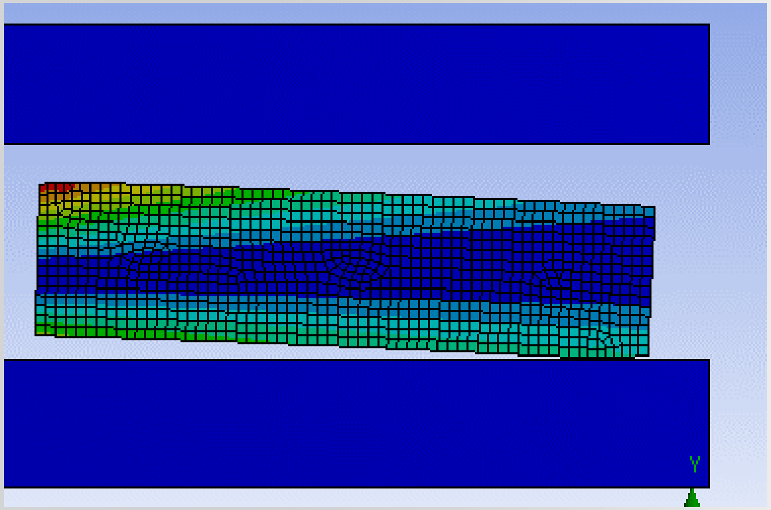


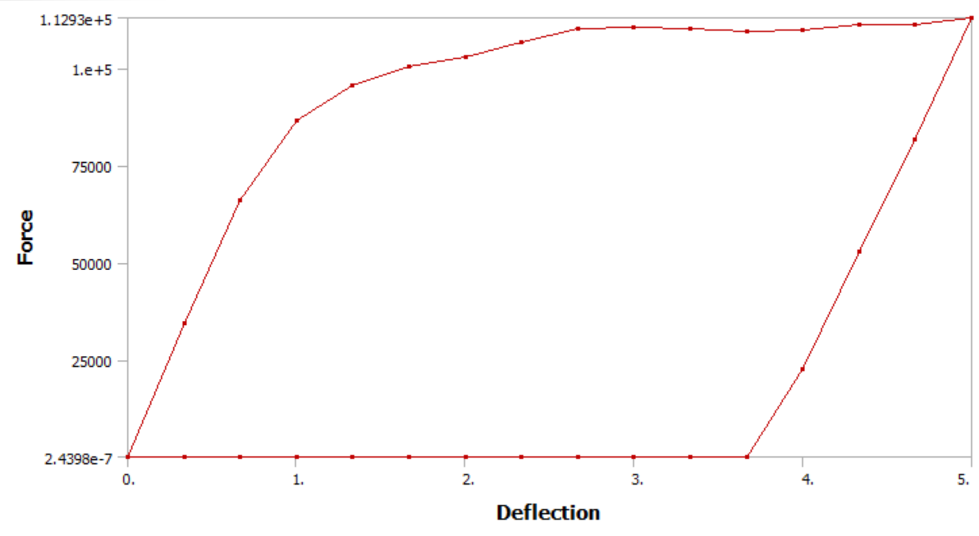
ANSYS Mechanical
Introduction to Structural Nonlinearities

Workshop 4A – Metal Plasticity

Goal:

- Define a nonlinear metal plasticity material for a belleville spring geometry and simulate "spring back" upon application of and subsequent removal of a displacement load.
- Post process stress and strain results
- Generate a force vs. deflection curve on the spring.





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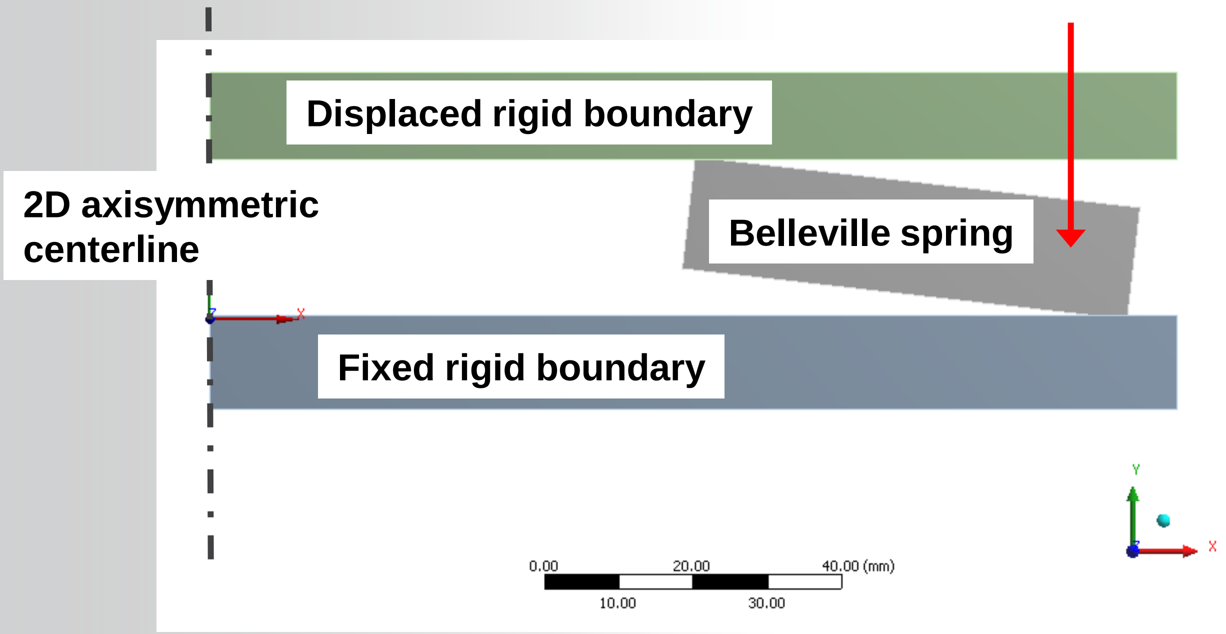
2D axisymmetric geometry

- The spring material is a ductile steel sandwiched between two rigid surfaces.
- Frictionless contact is assumed between the spring and the rigid geometries



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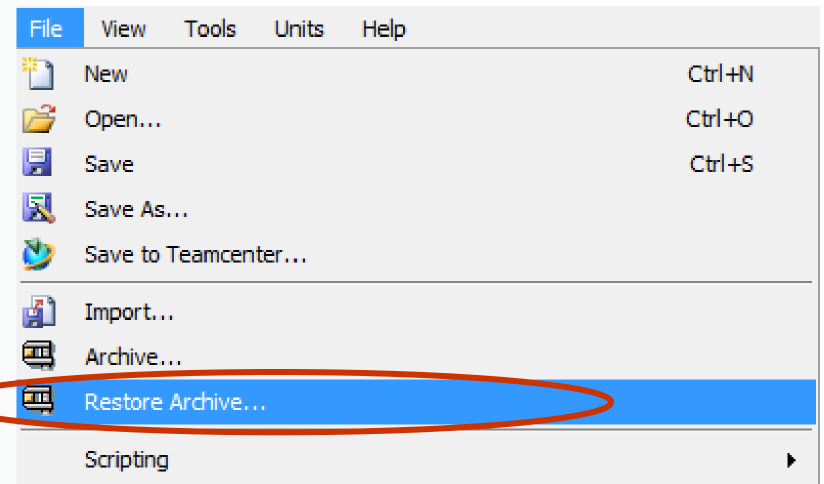
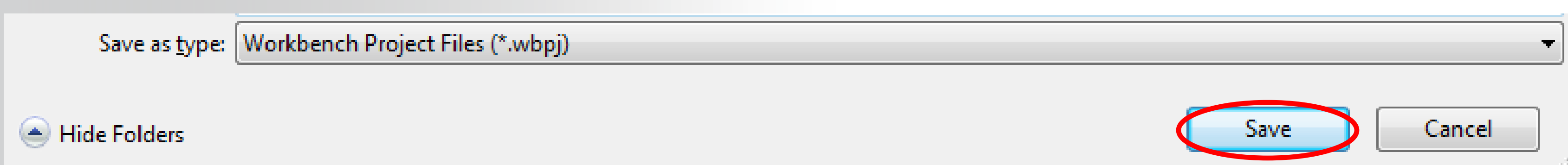
<u>Steps to Follow:</u>

Restore Archive… browse for file “SNL WS4a-belleville.wbpz”



Save as

- **File name: “WS4a-belleville”**
- **Save as type: Workbench Project Files (*.wbpj)**



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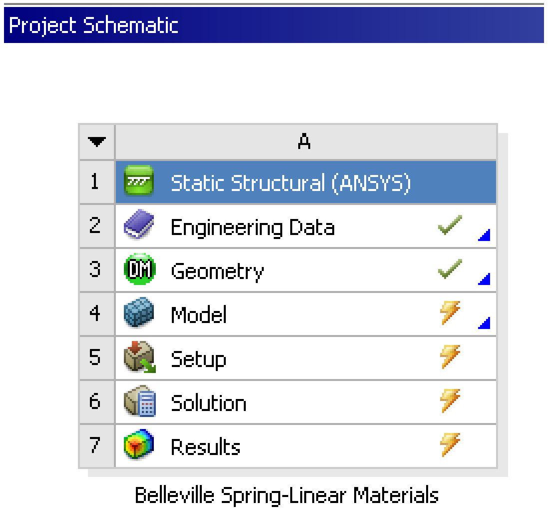
The project Schematic should look like the picture to the right.

- From this Schematic, you can see that Engineering (material) Data and Geometry have already been defined (green check marks).
- It remains to set up and run the FE model in Mechanical



- Open the Engineering Data Cell (highlight and double click OR Right Mouse Button (RMB)>Edit) to verify the linear material properties.
- Verify that the units are in Metric(Tonne,mm,…) system. If not, fix this by clicking on…
  - Utility Menu > Units > Metric(Tonne, mm,…)

Properties of Outline Row 3: Structural Steel

	A	B	C
1	Property	Value	Uni
2	Density	7.85E-09	tonne mi
3	Coefficient of Thermal Expansion		
4	Coefficient of Thermal Expansion	1.2E-05	C^-1
5	Reference Temperature	22	C
6	Isotropic Elasticity		
7	Young's Modulus	2E+05	MPa
8	Poisson's Ratio	0.3	
9	Alternating Stress Mean Stress	Tabular	
10	Scale	1	

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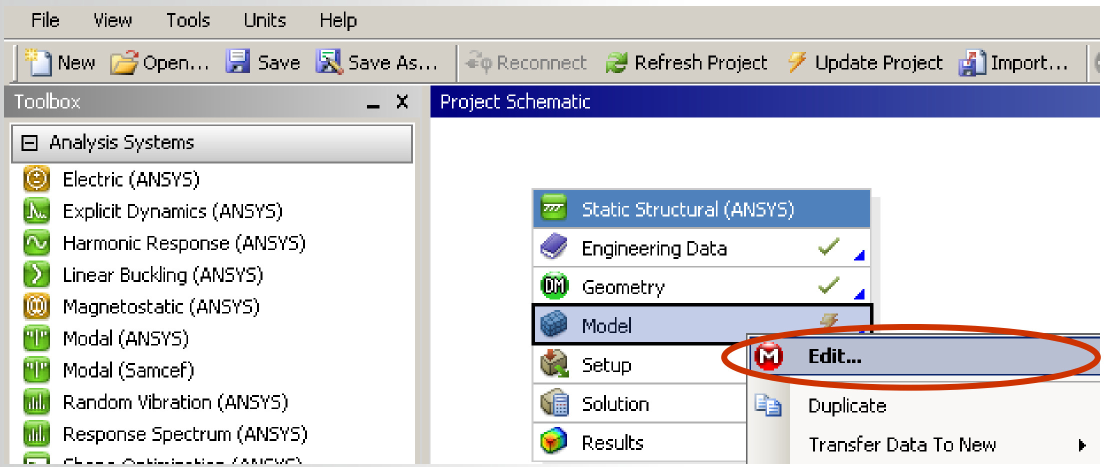
Return to the Project Page.

Double click on the Model Cell to open the FE Model (Mechanical Session) (or RMB=>Edit…)



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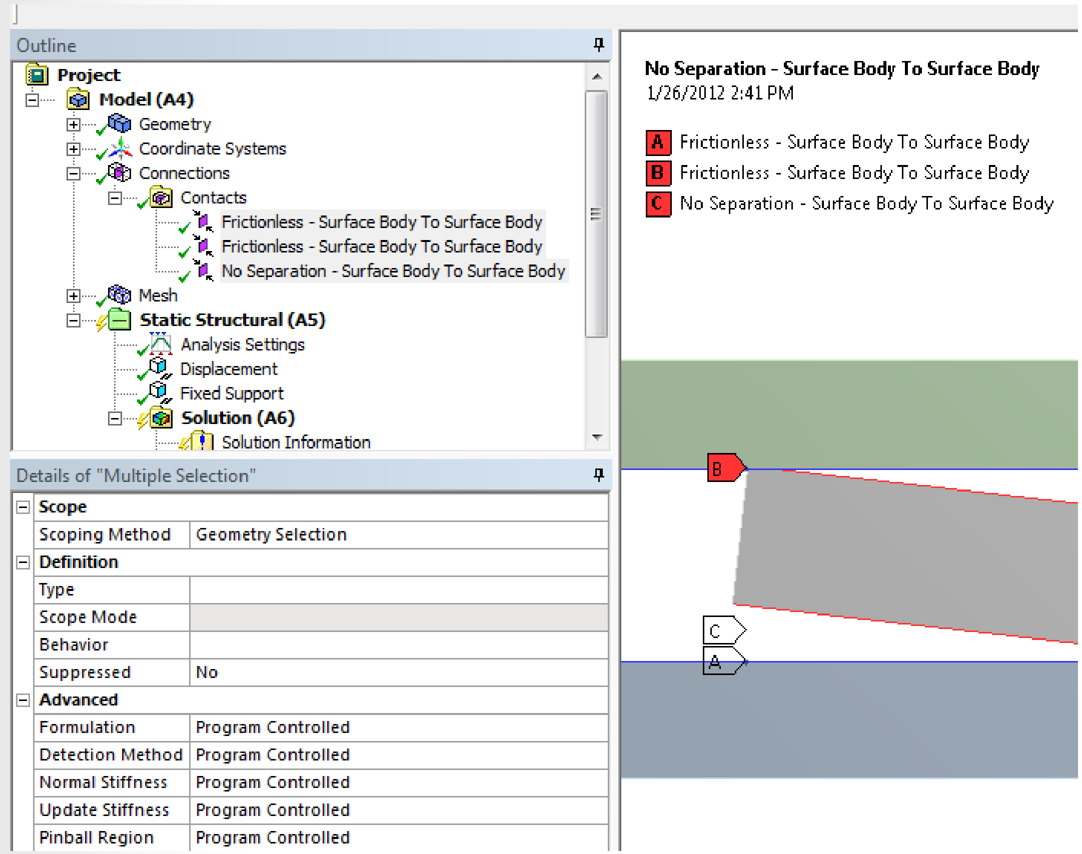
Open the folders beneath the model branch to become familiar with the model set-up.

Highlight “Geometry” and refer to the details window to verify that this is a 2D axisymmetric model.

Inspect the two asymmetric frictionless contact regions on top and bottom of spring which interface with top and bottom rigid boundaries.

Inspect the no-separation contact region which ties down the spring at the bottom corner to prevent rigid body motion during unloading.



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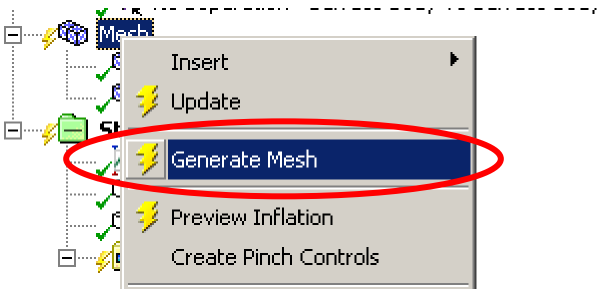
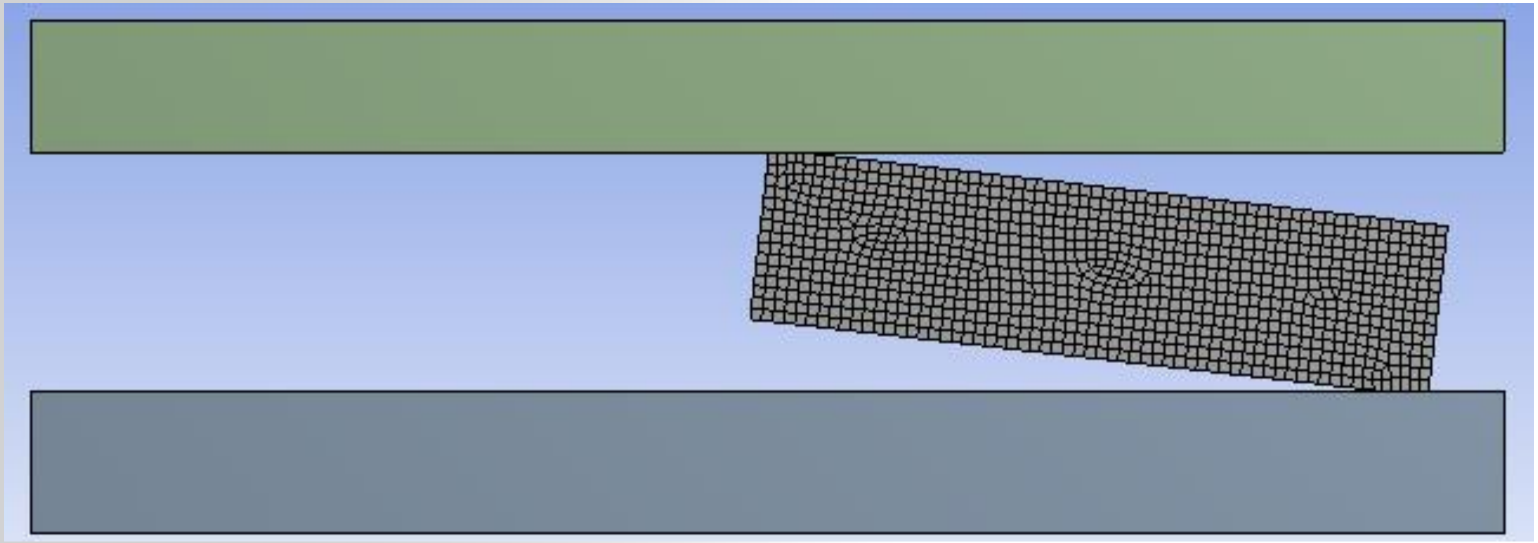
- **Review the mesh:**
  - **RMB>Generate Mesh**



The upper and lower geometries are meshed with one element each, while the belleville spring geometry is a free mesh.



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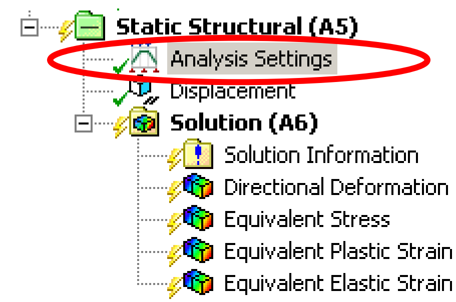
This is going to be a 3 load step analysis:

With the bottom plate fixed:
LS1: Null Solution (to generate results at origin for force-deflection plot)
LS2: Apply displacement load (-5mm) to upper plate
LS3: Remove displacement load

- **Confirm the following Analysis Settings:**
  - **Number of Steps:** ***3***
  - **Weak Springs:** ***Off***
  - **Large Deflection:** ***On***

For Current Step Number =1, Auto Time Stepping *On and with Initial, Minimum and Maximum Substeps = '1'.* (Null Solution)

For Current Step Numbers 2 and 3, Program Controlled for Auto Time Stepping.



Details of "Analysis Settings"

Step Controls	
Number Of Steps	3.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	On
Define By	Substeps
Initial Substeps	1.
Minimum Substeps	1.
Maximum Substeps	1.
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Off
Large Deflection	On
Inertia Relief	Off

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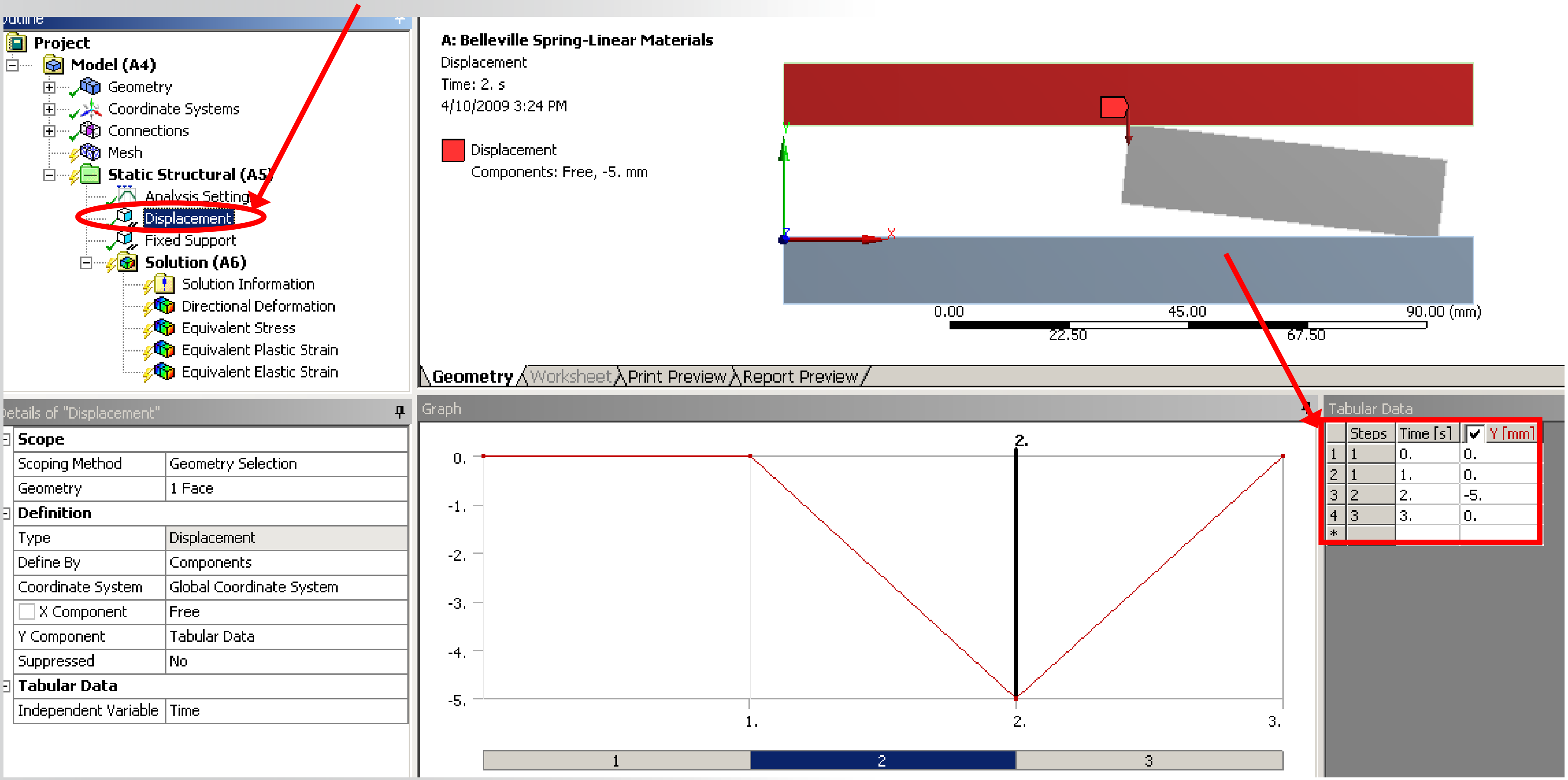
- **Review the predefined displacement load on the upper plate for the three load steps.**



  April 14, 2015

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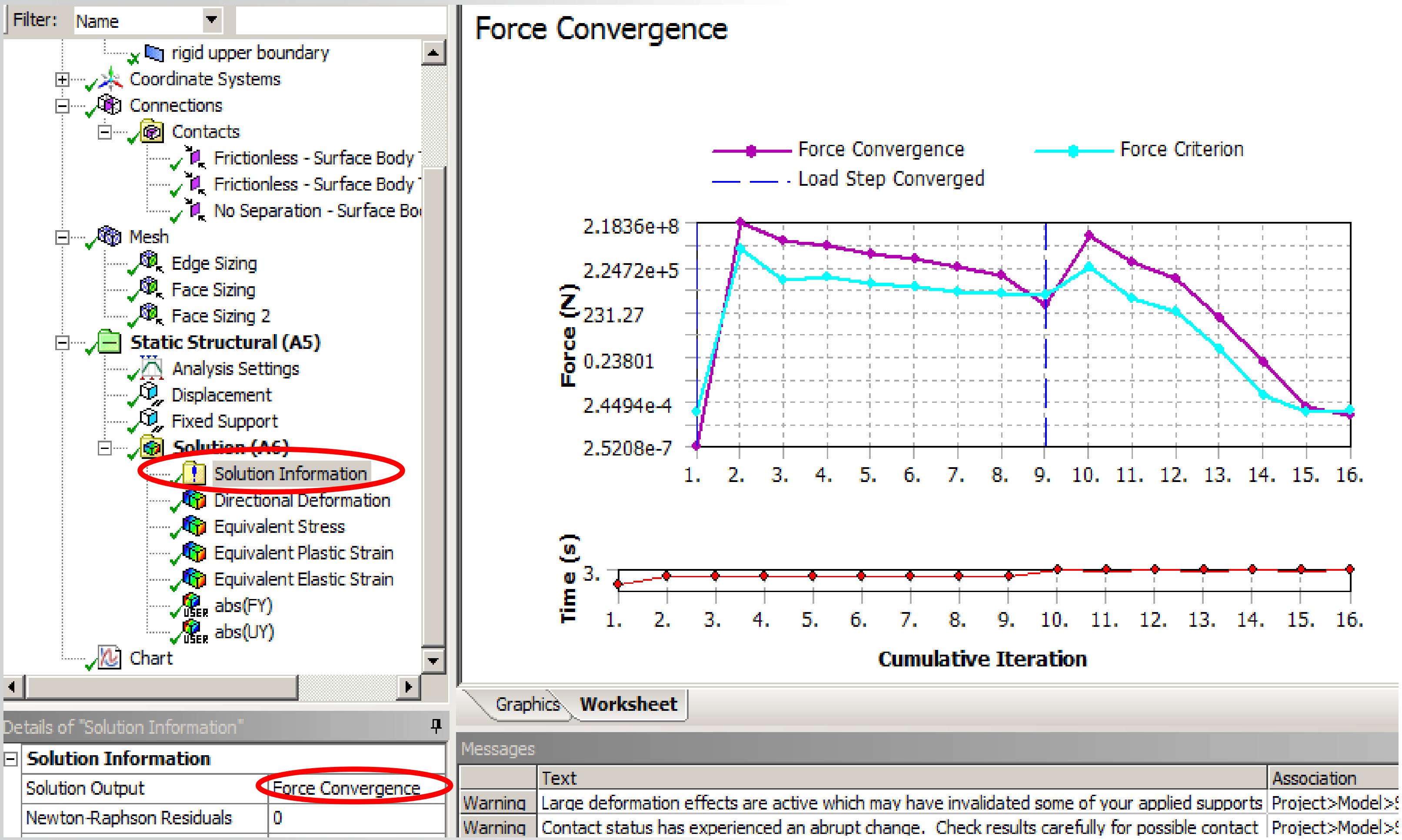
- **Execute Solve:** 

- **After solution is complete, review convergence history:**



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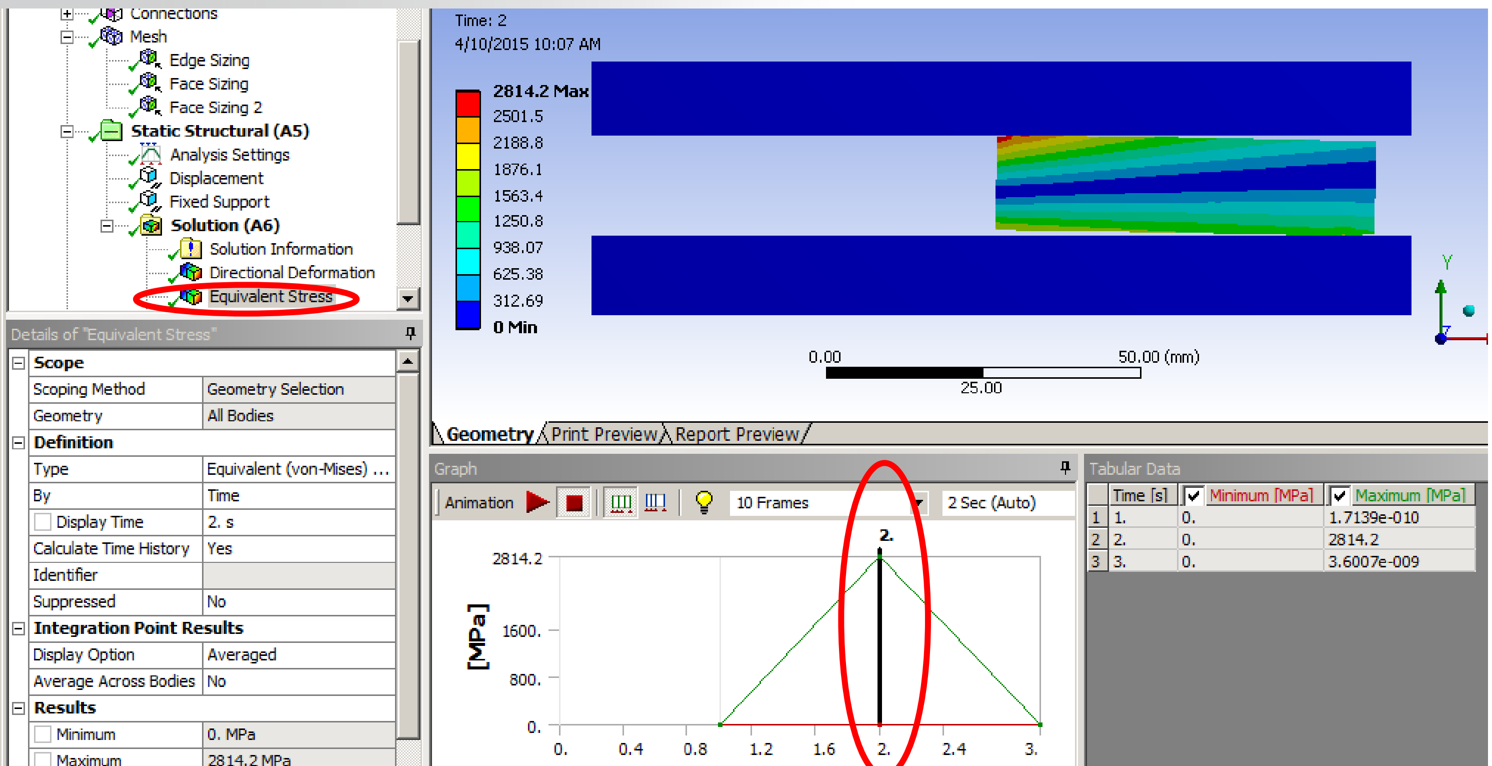
- **Post Process results at Load step 2:**
  - **Note how high the stress in the spring is at the end of LS2. Recall, this is still linear elastic material.**
  - **At LS3 (not shown), plastic strain is zero and there is no permanent deformation of the spring upon unloading as expected.**



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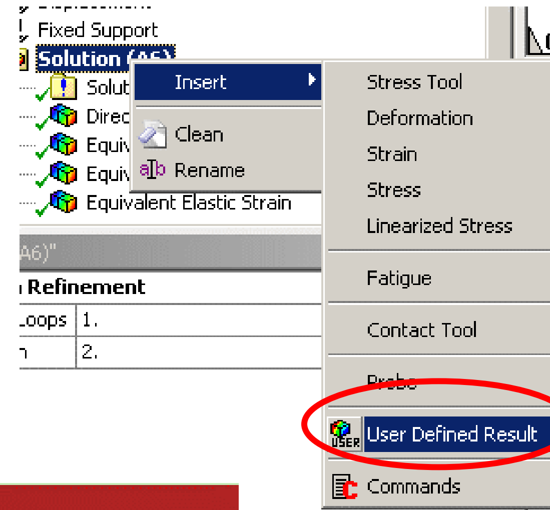
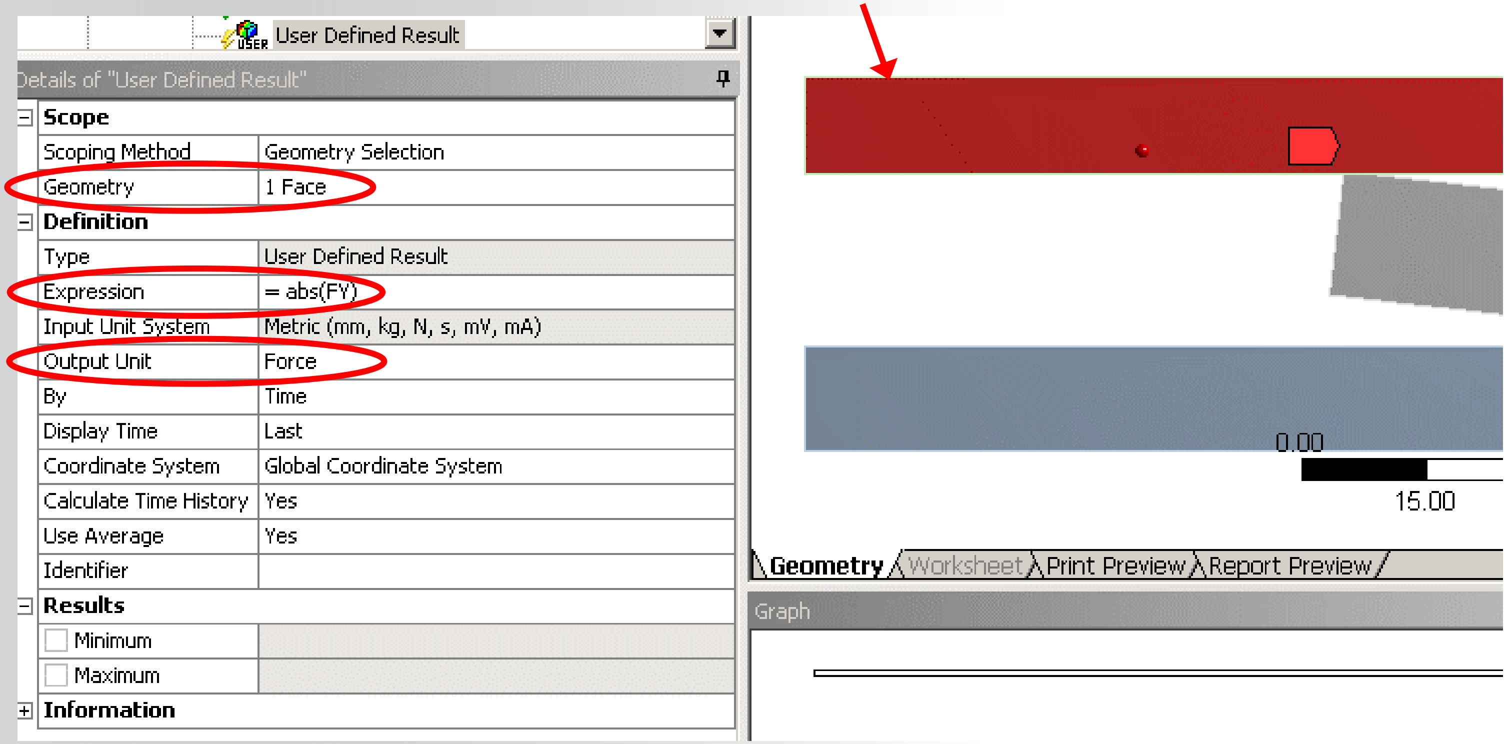
- **Generate Force vs. Deflection Curve of Spring**
  - **With Solution Branch Highlighted:**
    RMB>Insert>User Defined Result
  - **Scope result to the upper rigid plate**
  - **Define the expression as ‘abs(FY)’ for absolute value of force in Y-direction**





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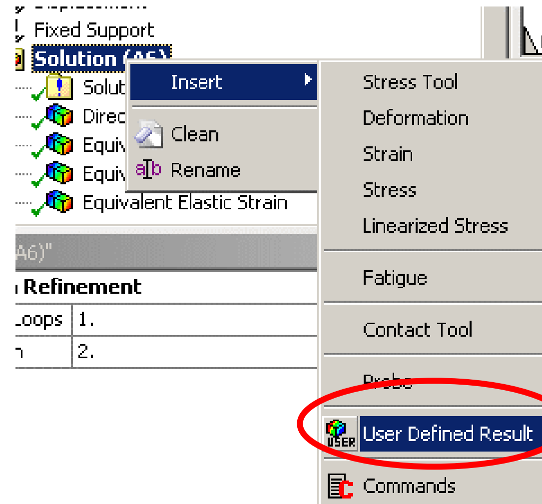
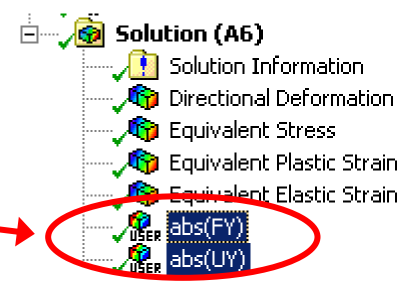
Repeat Procedure for Displacement in 'UY'

Details of "abs(UY)"

Scope	
Scoping Method	Geometry Selection
Geometry	1 Face
Definition	
Type	User Defined Result
Expression	= abs(UY)
Input Unit System	Metric (mm, kg, N, s, mV, mA)
Output Unit	Length
By	Time
Display Time	Last
Coordinate System	Global Coordinate System
Calculate Time History	Yes
Identifier	
Suppressed	No





– **Highlight both User Defined Results:**

RMB>Rename based on Definition

– **Highlight Solution Branch:**

RMB>Evaluate results

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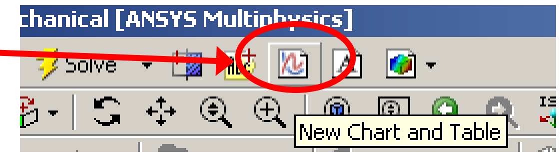
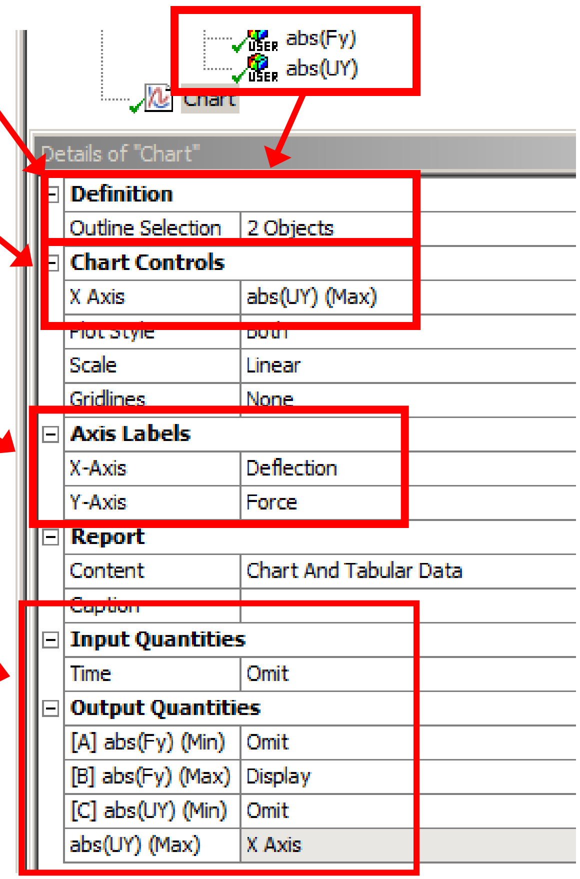
Insert a Chart Tool for plotting FY vs UY



- Fill in Chart tool Details Window as Follows:
  - Definition: Select 'abs(FY)' and 'abs(UY)' from Solution Branch
  - Chart Tool: X Axis: abs(UY) (Max)
  - Axis Labels:
    - X-Axis Label: Deflection
    - Y-Axis Label: Force
  - Input & Output Quantities:
    - Omit: Time, abs(FY)(Min), abs(UY)(Min)



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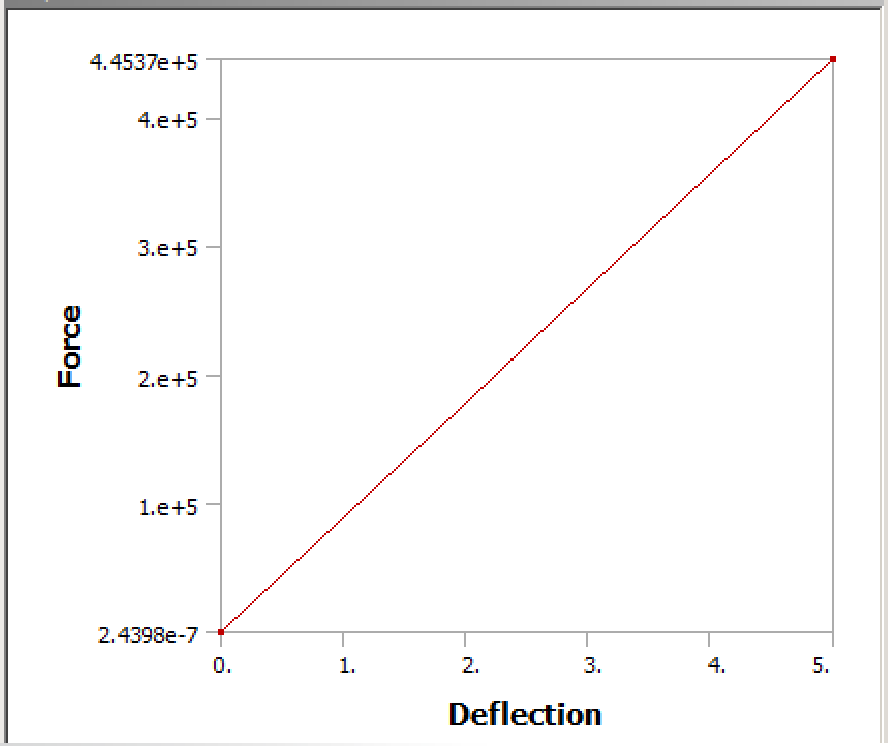
Resulting Chart of Force vs Displacement for linear material is a straight line with no permanent deformation as expected

Details of "Chart"

Definition	
Outline Selection	2 Objects
Chart Controls	
X Axis	abs(UY) (Max)
Plot Style	Both
Scale	Linear
Gridlines	None
Axis Labels	
X-Axis	Deflection
Y-Axis	Force
Report	
Content	Chart And Tabular Data
Caption	
Input Quantities	
Time	Omit
Output Quantities	
[A] abs(FY) (Min)	Omit
[B] abs(FY) (Max)	Display
[C] abs(UY) (Min)	Omit
abs(UY) (Max)	X Axis

Graph



Tabular Data

	Steps	Time [s]	[B] abs(FY) (Ma
1	1	1.	2.4398e-007
2	2	2.	4.4537e+005
3	3	3.	4.3029e-006

![ANSYS logo]

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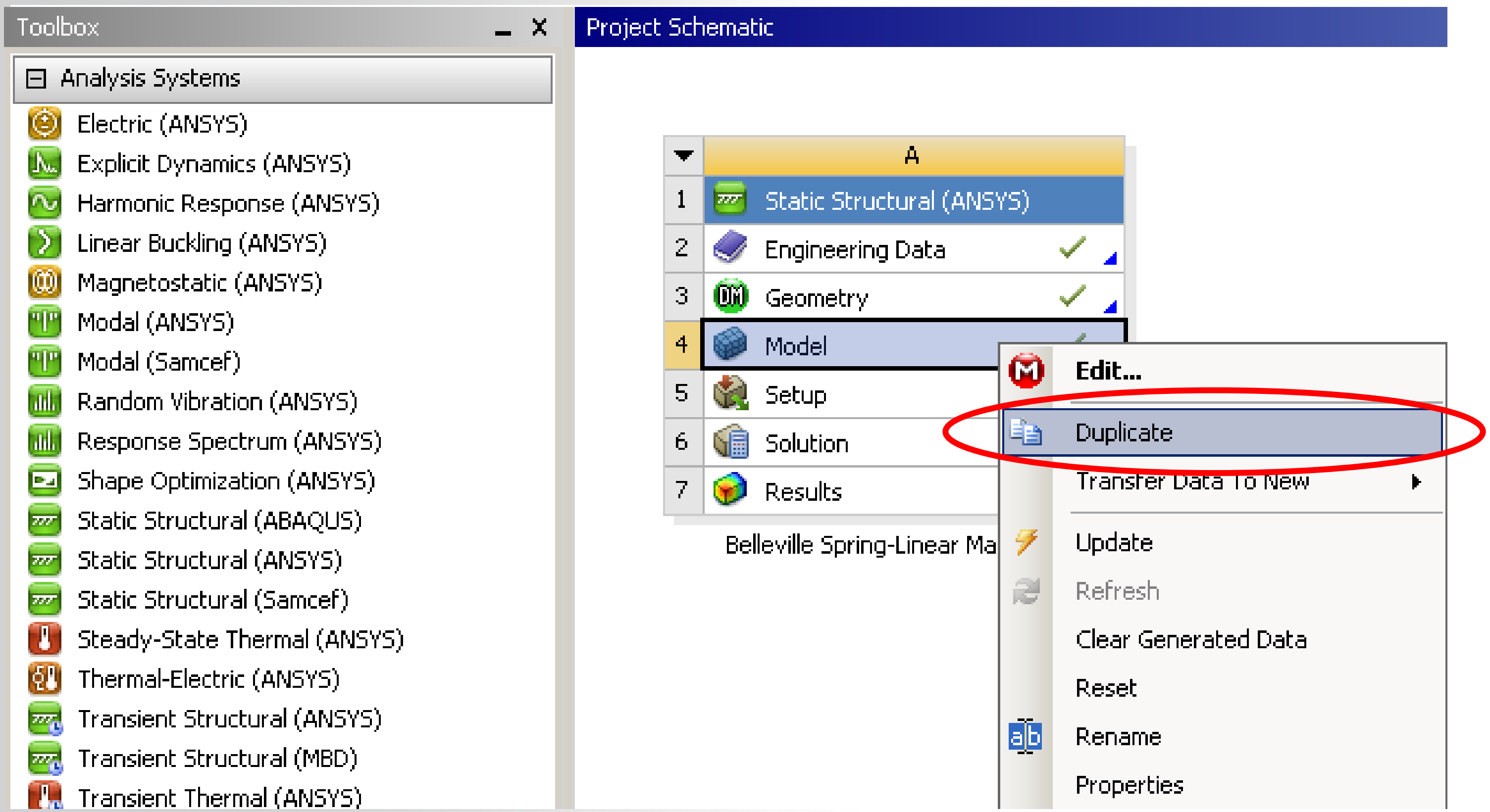
Duplicate the Static Analysis

- Return to the Project Schematic
- Highlight the Model Cell and RMB> Duplicate



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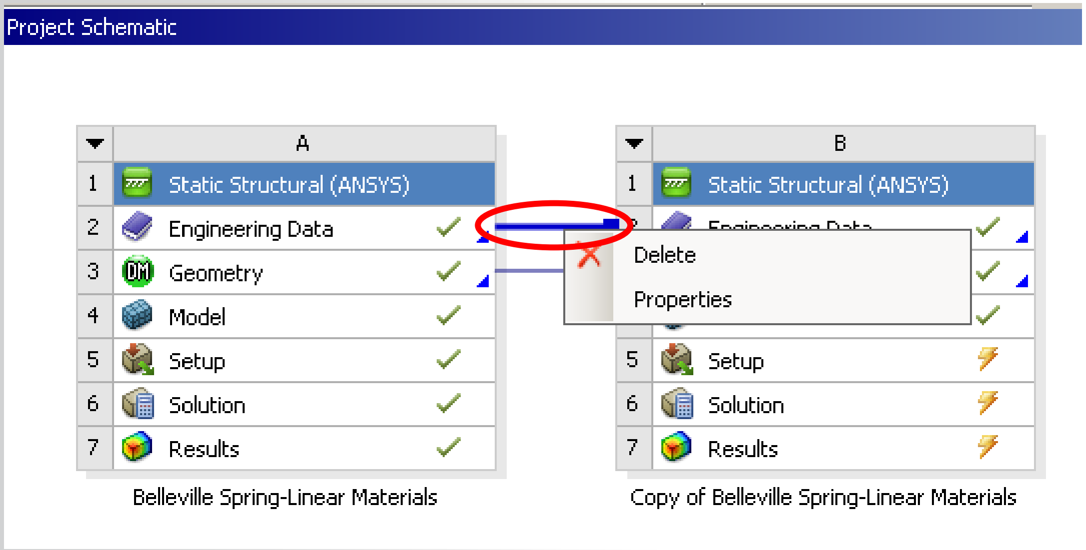
Disassociate material properties link

- The second analysis is going to be with metal plasticity defined
- Highlight the Engineering data link and RMB>Delete



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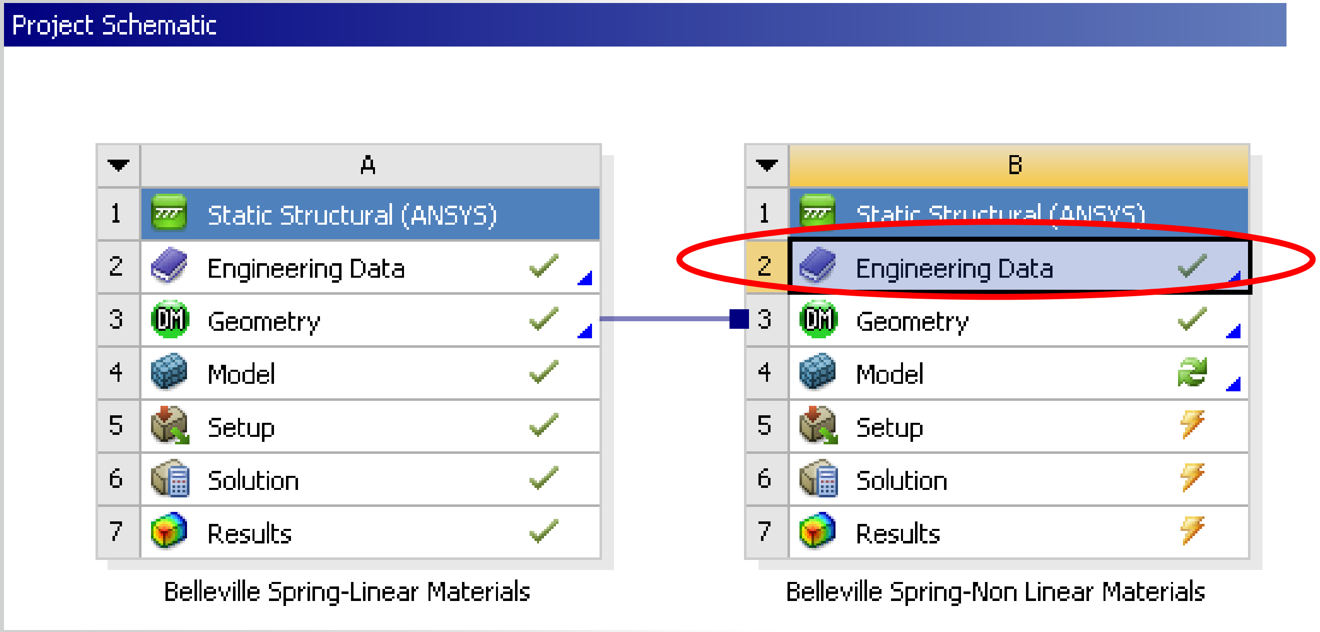
Project Schematic should now look like the diagram below

- We can now modify the Engineering data in Table B without effecting the model and/or results of Table A.
- Change the title of the new Analysis to:

  "Belleville Spring-Nonlinear Materials"
- Open the Engineering Data Cell in Table B



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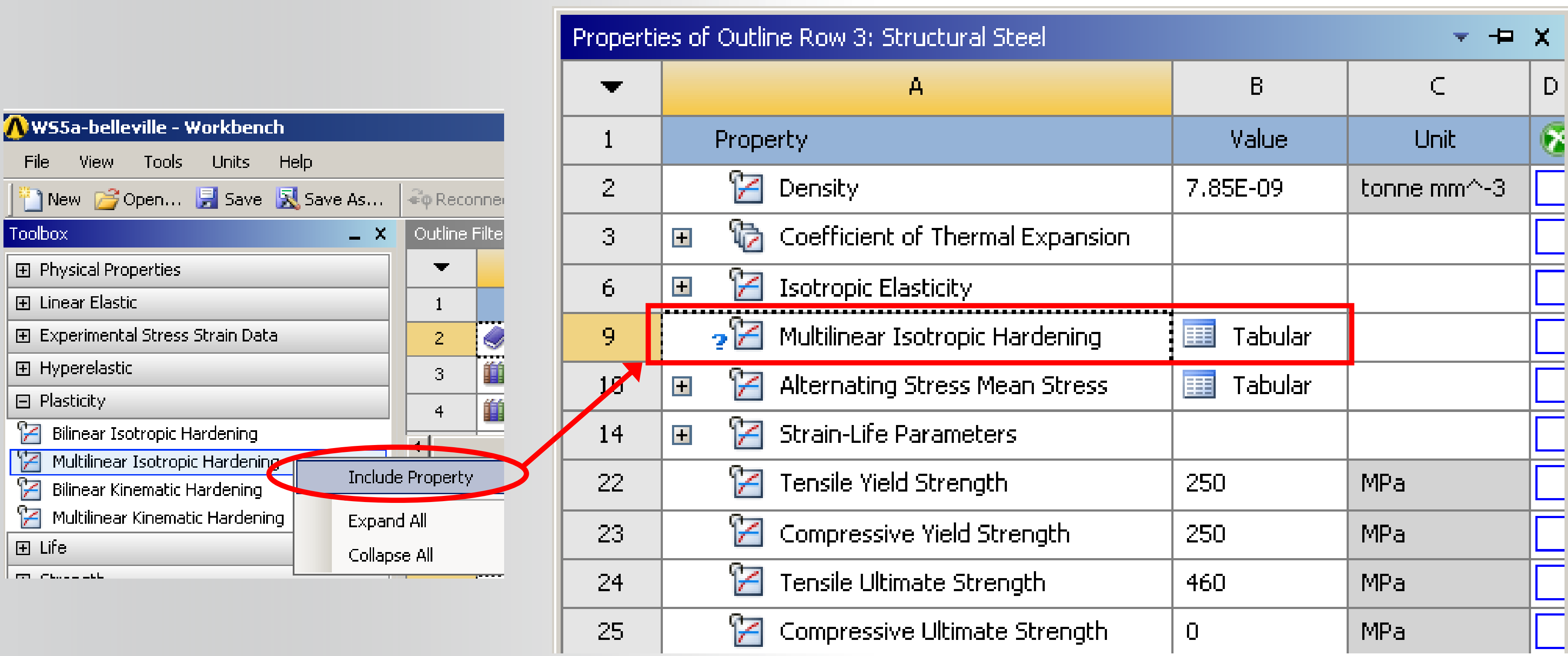
Insert a Metal Plasticity Model

- From the Tool Box, open the Plasticity Folder
- Highlight Multilinear Isotropic Hardening and RMB>"Include Property"
- The new material should now appear in the Properties dialogue box



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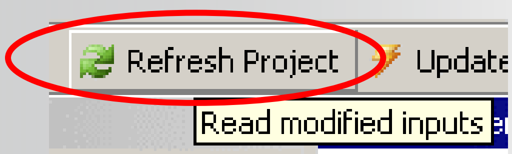
Define Plasticity data

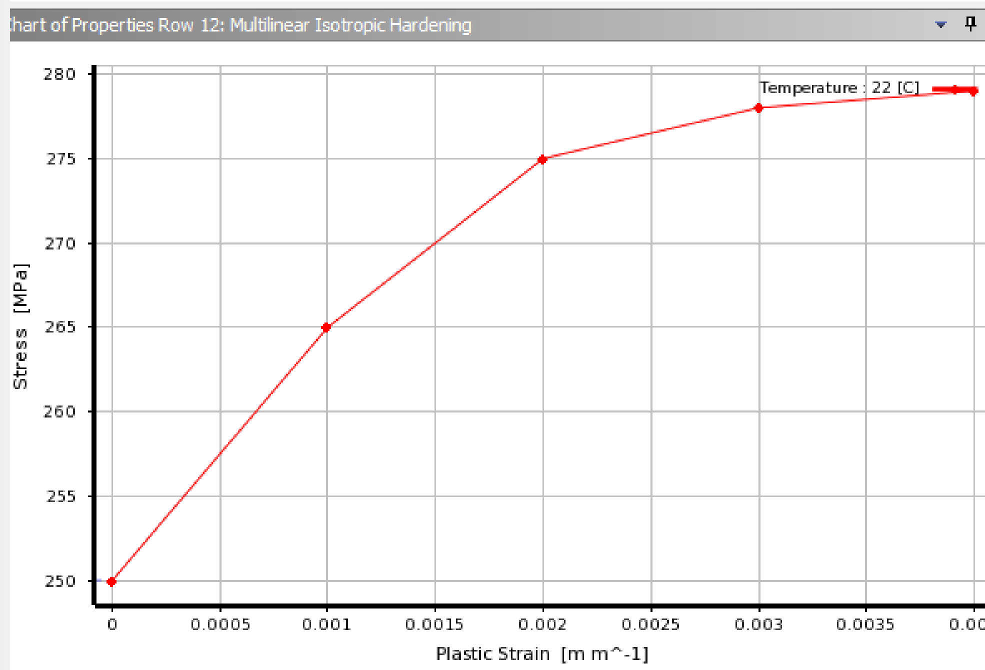
- Fill in plastic strain and stress data as shown to the right
- From the Utility Menu, read in the modified material properties with
- Return to Project Workspace
  - Refresh Project



able of Properties Row 12: Multilinear Isotropic Hardening

	A
1	Temperature (C)
2	22
*	

	B	C
1	Plastic Strain (m m^-1)	Stress (MPa)
2	0	250
3	0.001	265
4	0.002	275
5	0.003	278
6	0.004	279
*		



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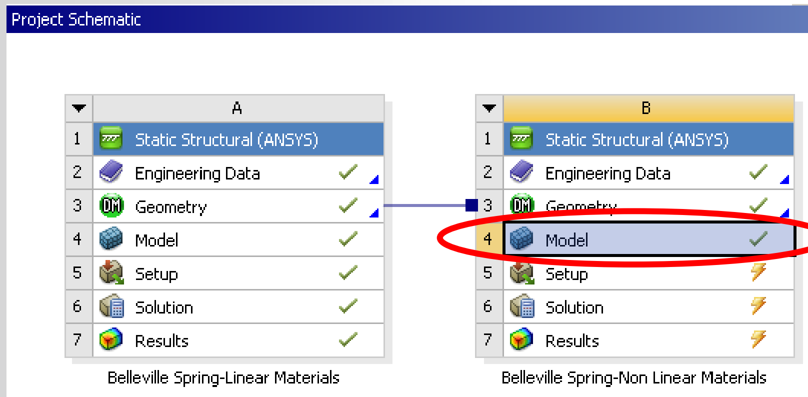
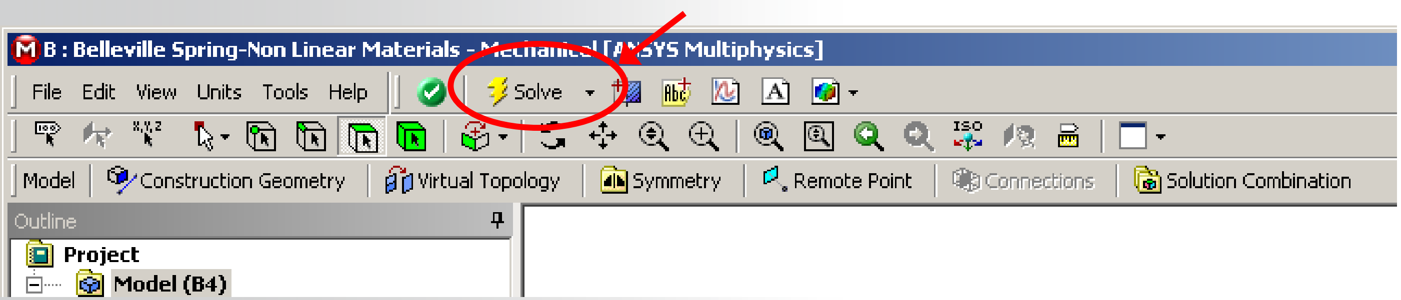
From the project schematic, highlight and open the model cell in Table B.



All the geometry entities, meshing specs, boundary conditions, loads and analysis settings are preserved from the previous analysis.

– Execute the Solve with the newly defined plasticity properties



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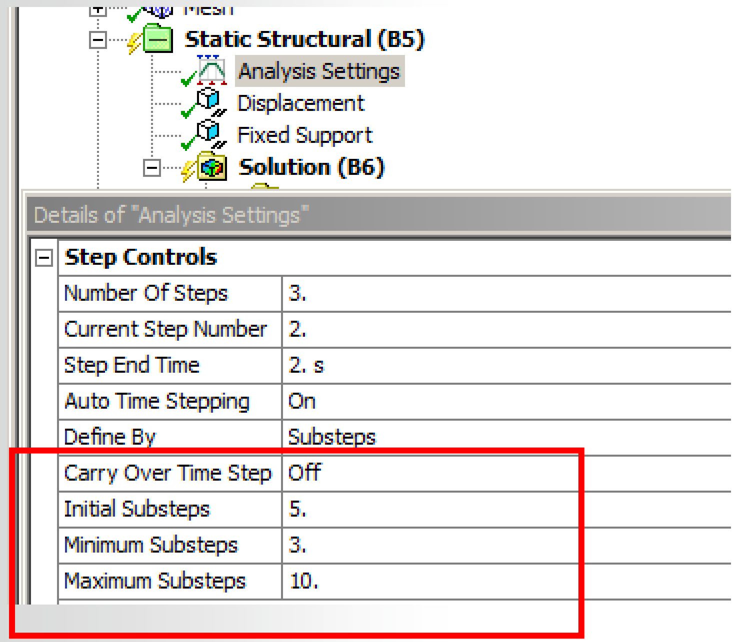
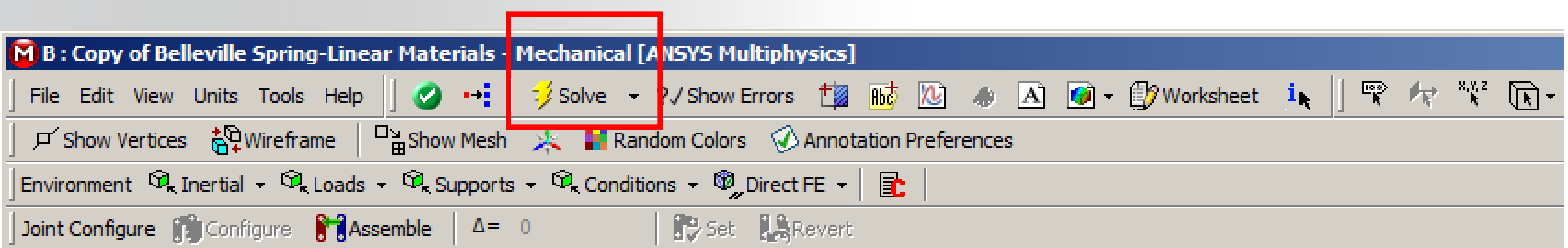
Return to Analysis Settings. For LS 2 and 3 specify the following for autotime stepping:



Execute Solve…



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- **After solution is complete, review Solution output:**
  - **Confirm that the metal plasticity, as defined, was included in this new run**

```
PLASTIC  (PLAS) Table For Material     3

  ISOTROPIC HARDENING PLASTICITY

       Temperature = 22.000000

   Point        PlStrain        Stress
       1     0.000000e+000   2.500000e+002
       2     1.000000e-003   2.650000e+002
       3     2.000000e-003   2.750000e+002
       4     3.000000e-003   2.780000e+002
       5     4.000000e-003   2.790000e+002
```

```
*** MAX PLASTIC STRAIN STEP = 0.3968E-02   CRITERION = 0.1500
*** AUTO TIME STEP:  NEXT TIME INC = 0.30000      INCREASED (FACTOR = 1.5000)
```

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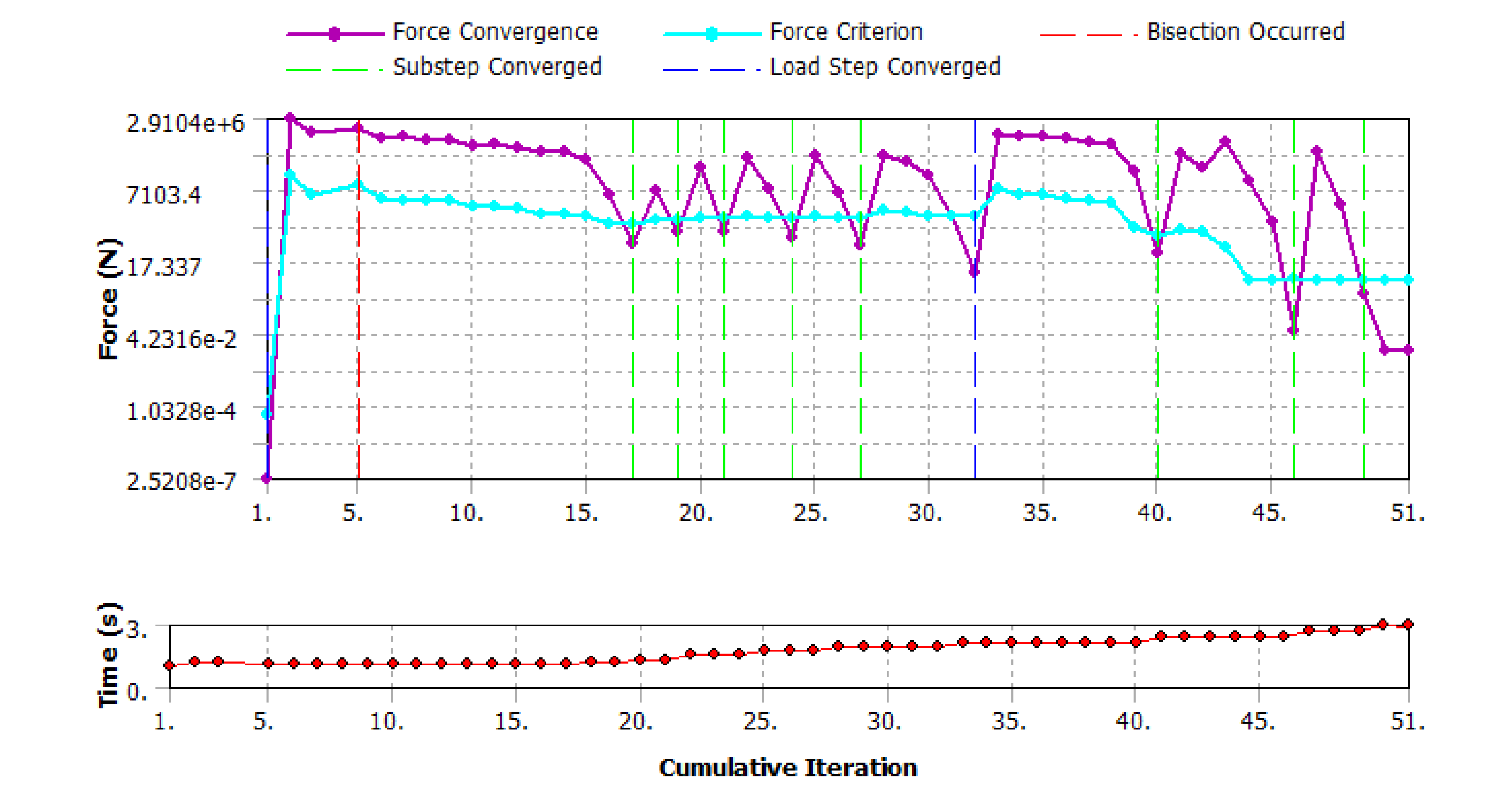
- **Review the Convergence History. Compare this with the Linear material run.**



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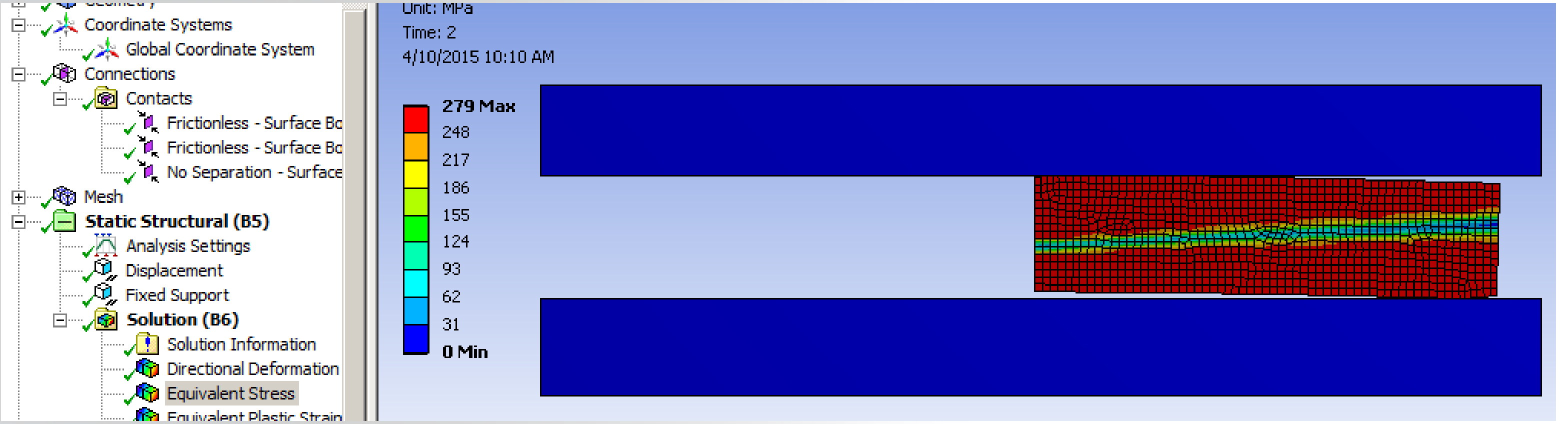
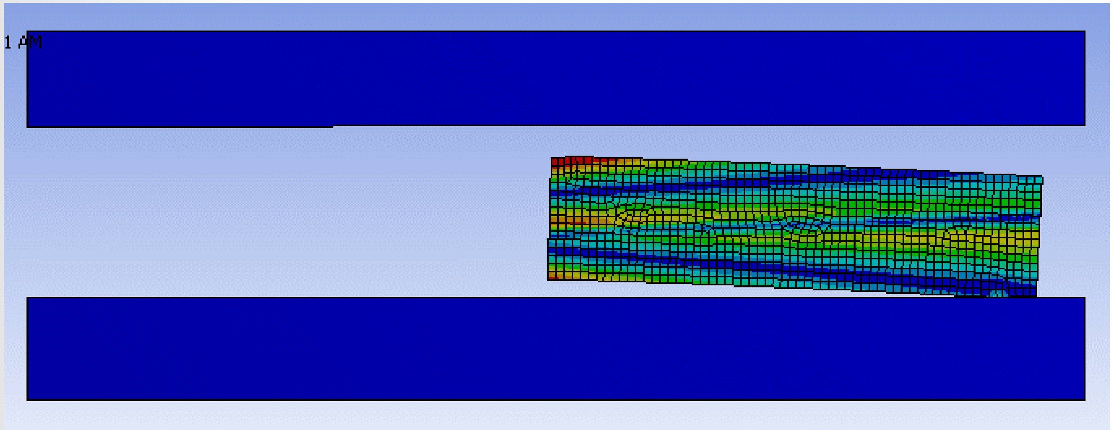
- Post Process results at Load step 2 as before:
  - Compare the max stress in this material with the linear material



  - Note also that the spring now takes a permanent set after load is removed as expected.



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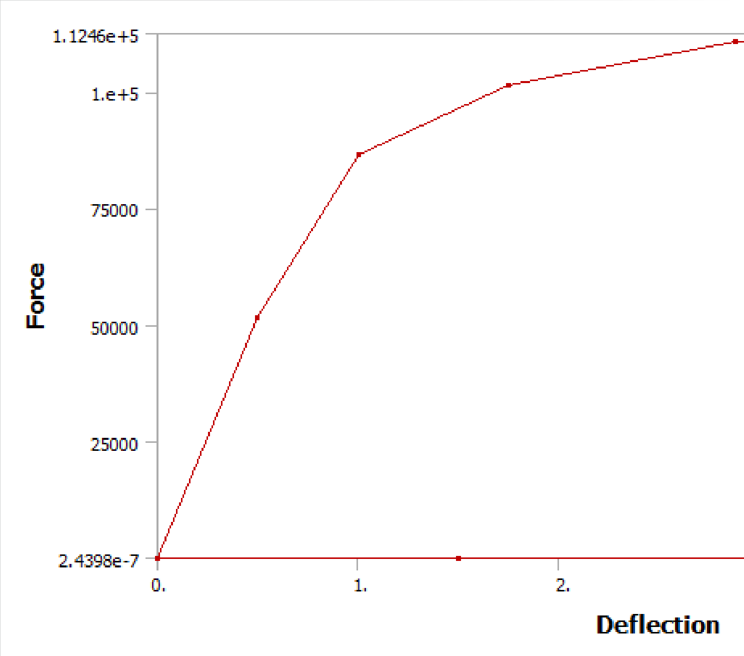
- Highlight the Chart tool and Plot Force vs Deflection as before.
  - Note the nonlinear path of the curve reflecting the influence of the material yielding and taking a permanent set.
  - Note also the difference in the magnitude of the load required to produce the same deflection with this material verses the linear material, underscoring the importance of considering nonlinear material behavior in some designs.



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- **To improve the quality of the force deflection curve, try rerunning the analysis using a minimum of 15 substeps for LS 2 and 3.**