Lab #9

Selected Nonlinear Problems

The City College of New York

Department of Mechanical Engineering

ME 37100 Computer Aided Design

Section 1EF

Instructors: Yesim Kokner

Sarah Liu

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## Table of Content



## Abstract

Non-linearity under load can be caused by material, initial conditions and large displacements. A variety of cases will be examined that causes such nonlinearity. Such analysis can be done both by proper constraints in a static study or by directly using nonlinear studies when doing FEA analysis.

## Introduction

A variety of different studies is available through FEA. The simplest, static studies assume a constant loading case that does not account for changes over time. For certain cases, where load and nonchanging stiffness is assumed, such study would be sufficient. However, variability may also be considered and cannot be accurately represented by static case.

During loading cases, it is not always necessarily true that stiffness will remain constant throughout. Nonlinearity can be due to materials with low elasticity, an excessive displacement that occurs or due to the applied load and initial conditions.

## Theoretical Background

Materials can cause nonlinearity when it comes to the way displacement is distributed. A material property can only be described as linear in its elastic region, with the defining elastic modulus to account for the linear behavior, however, once reaching the plastic region the E value becomes 0. Materials with lower yield strength are more susceptible to nonlinearity when facing the same loading due to this reason [3].

The geometry of the part can be a source of nonlinearity by creating large displacements. Thus, such cases allow static studies to properly analyze the loading case by simply accounting for the large displacements. By increasing the displacements beyond that of a static case, the total stiffness would vary along the material.

The application of loading may not be static and therefore cause nonlinearity. With just a static study, load can be applied once, due to the assumption of a single non variable load. However, if such loading either varies over time or may change, multiple runs must be done to fully capture the change and therefore nonlinearity of the loading.

## Graphical Demonstrations of SolidWorks Results

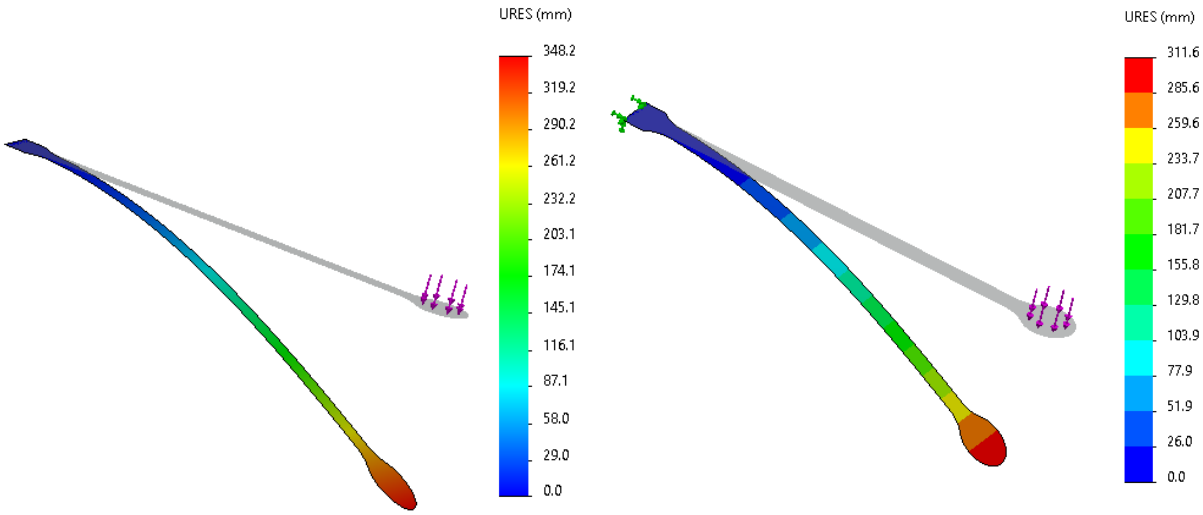


Figure 1: (A) NL002 model with linear displacement (left) and (B) Nonlinear displacement (right) plots

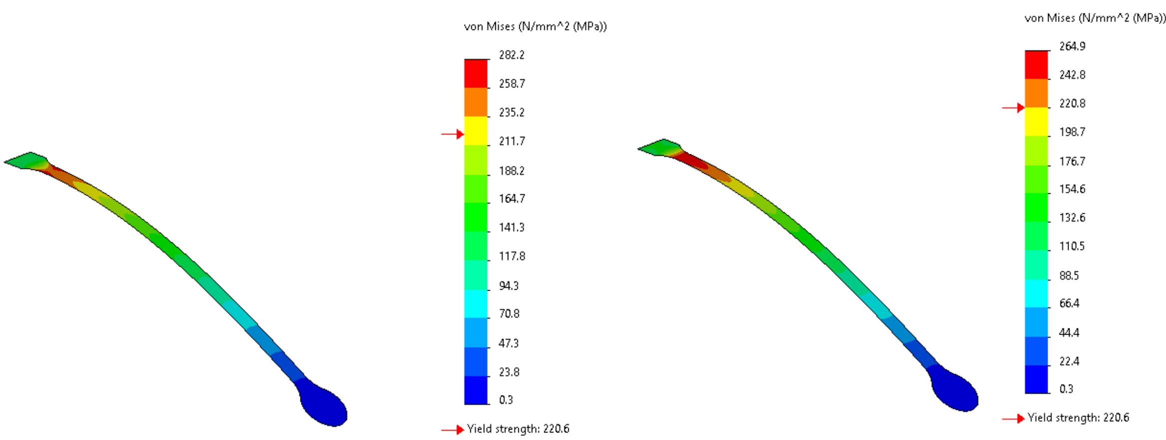


Figure 2: Nonlinear von Mises stress plot on the (A) bottom shell (left) and (B) top shell (right)

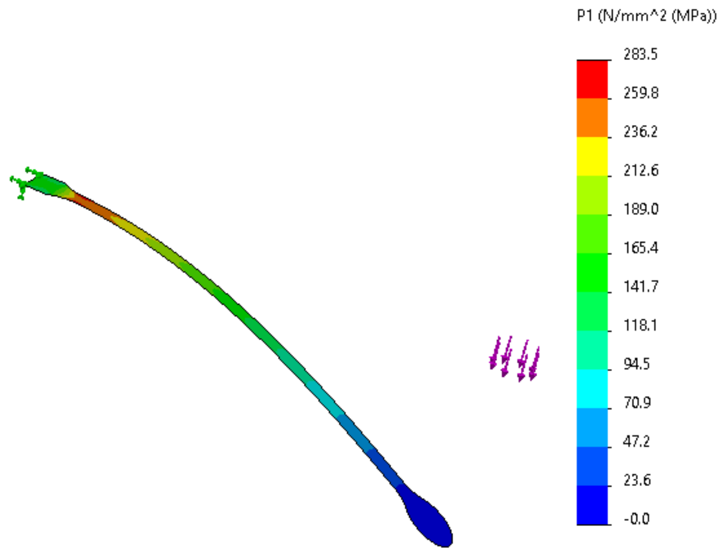


Figure 3: Nonlinear P1 stress plot on the bottom shell

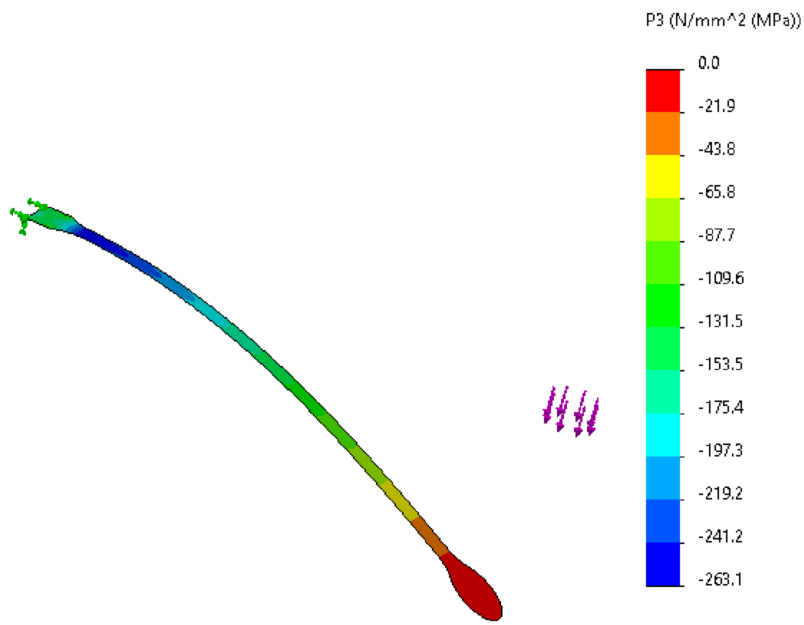


Figure 3: Nonlinear P3 stress plot on the top shell

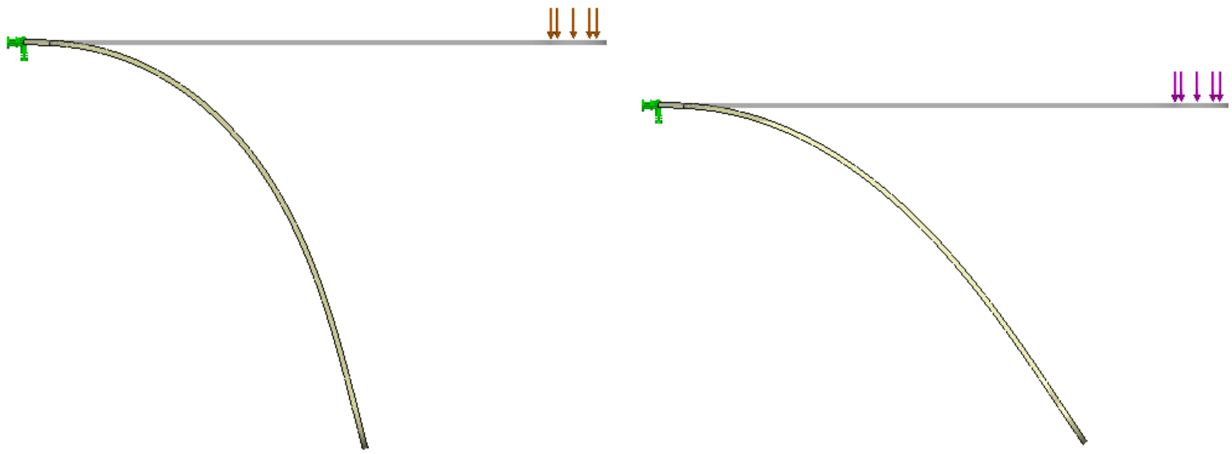

Figure 4: (A) Nonlinear following (left) and (B) Non-Linear not following (right)

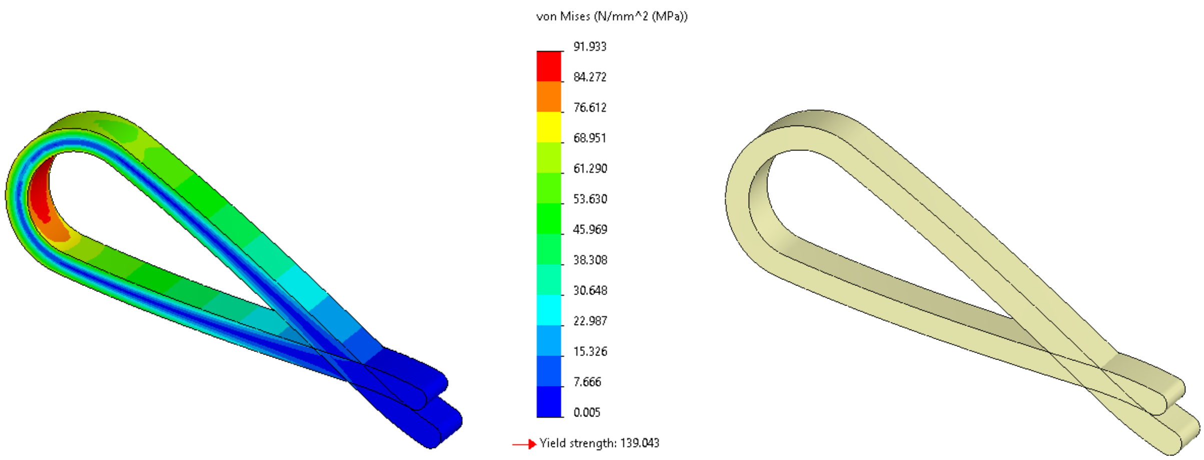


Figure 5: Clip linear von Mises Stress plot

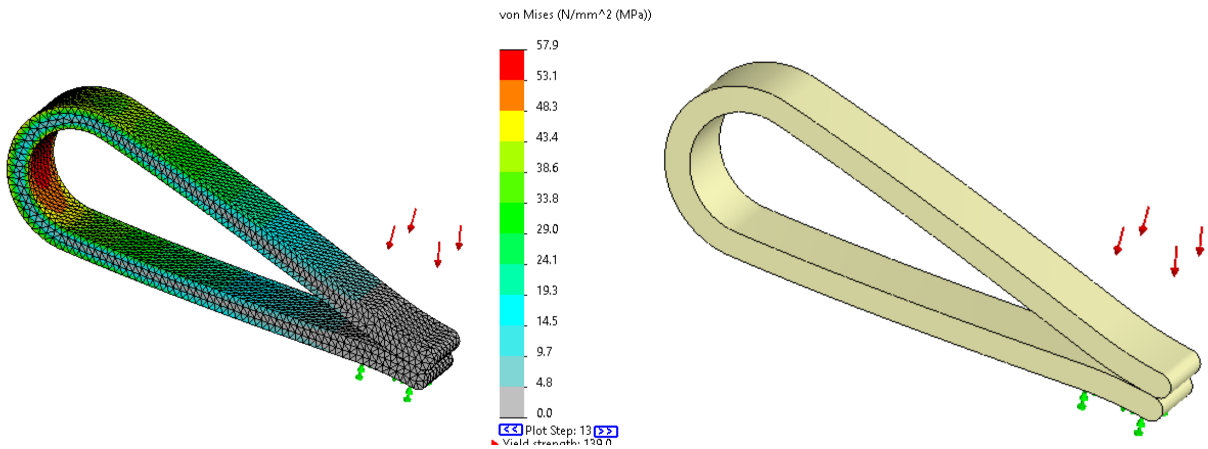


Figure 6: Clip nonlinear von Mises Stress plot

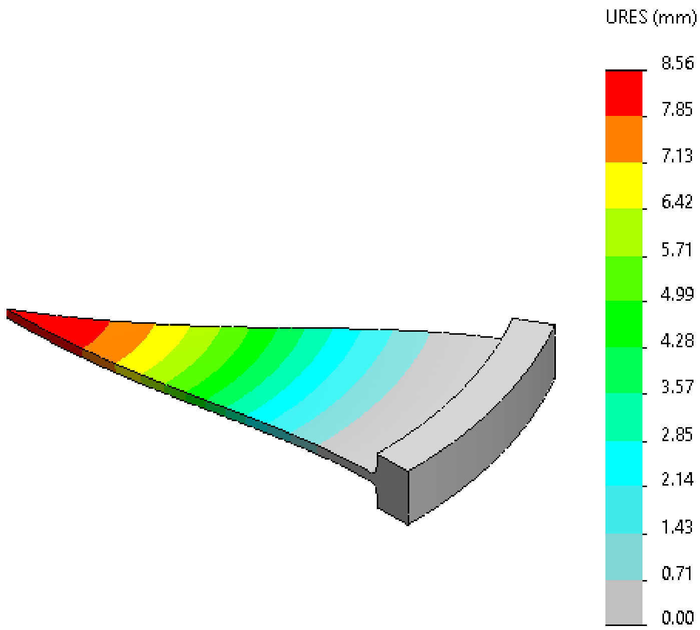


Figure 7A: Round flat plate linear displacement plot

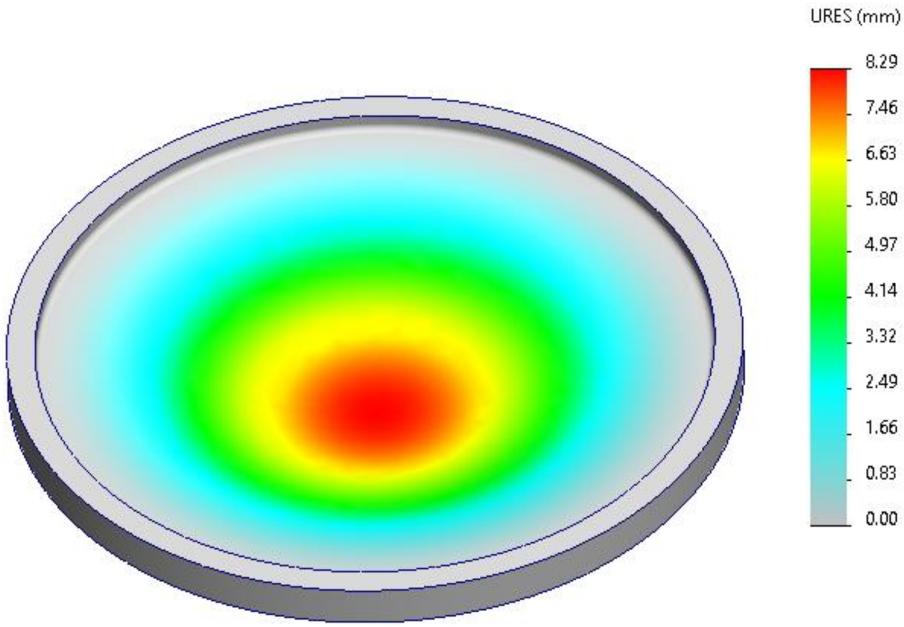


Figure 7B: Full Model Round flat plate linear displacement plot

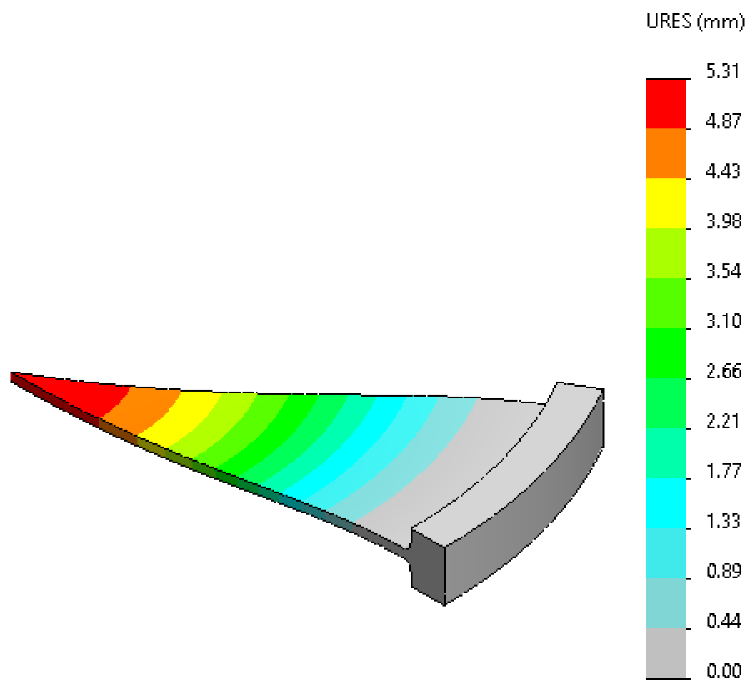


Figure 8A: Round flat plate nonlinear displacement plot

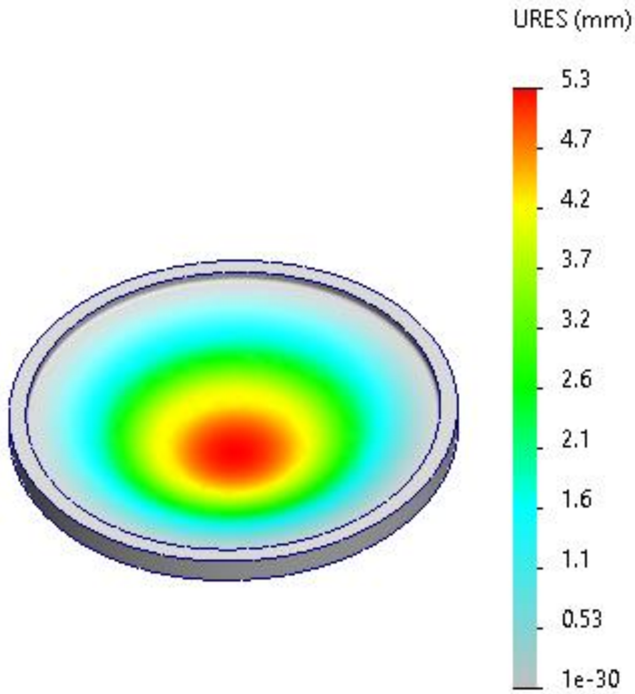


Figure 8B: Full Model Round flat plate nonlinear displacement plot

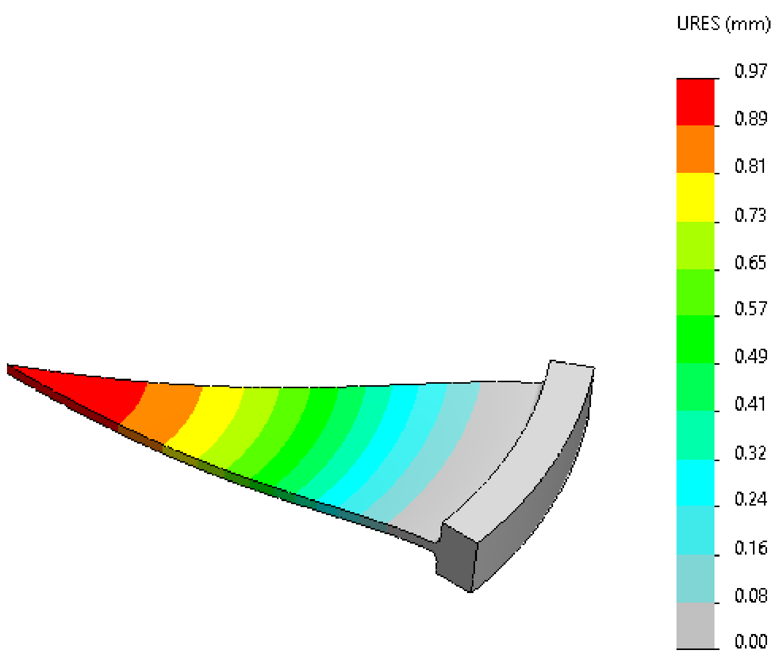


Figure 9A: Round curved plate linear displacement plot

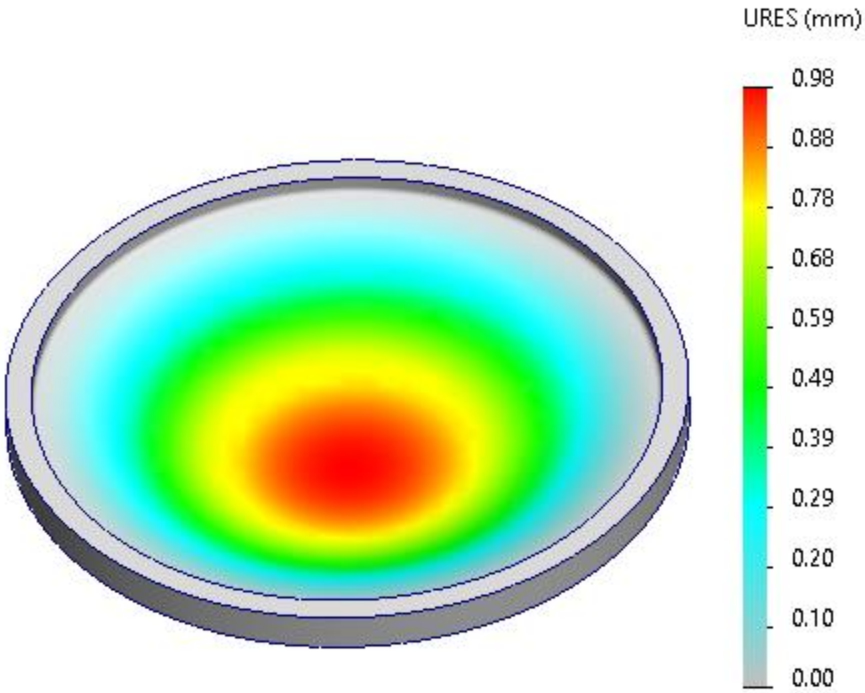


Figure 9B: Full Model Round curved plate linear displacement plot

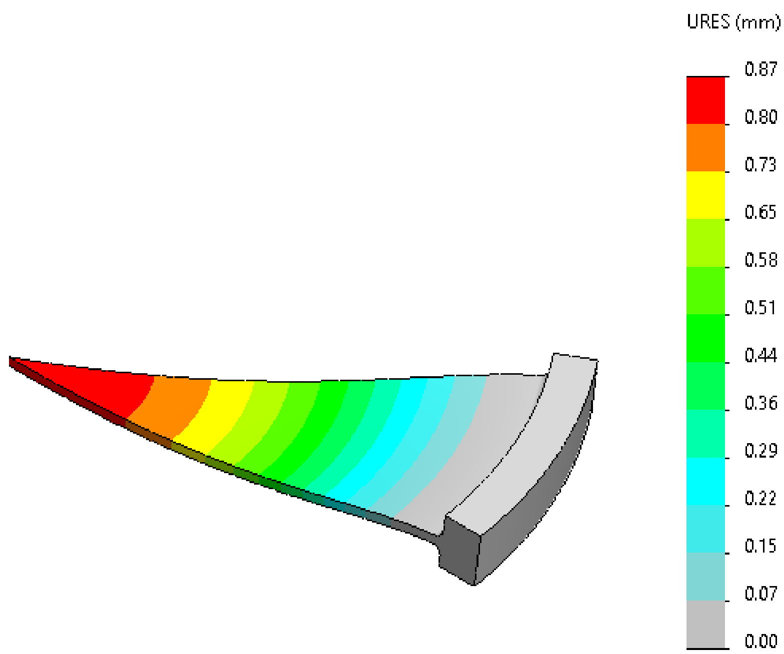


Figure 10A: Round curved plate nonlinear displacement plot

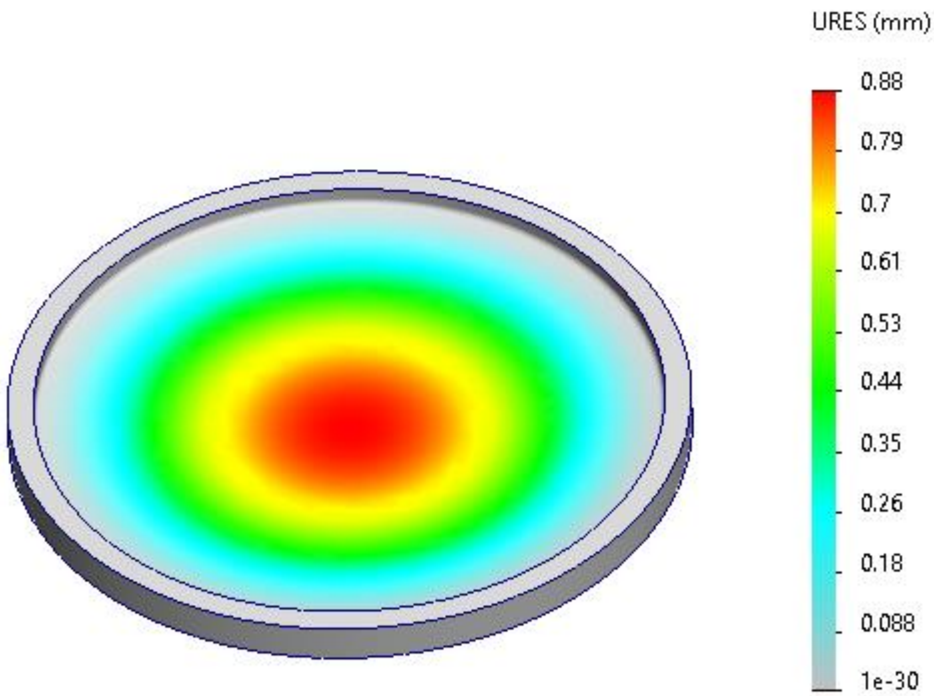


Figure 10B: Full round curved plate nonlinear displacement plot

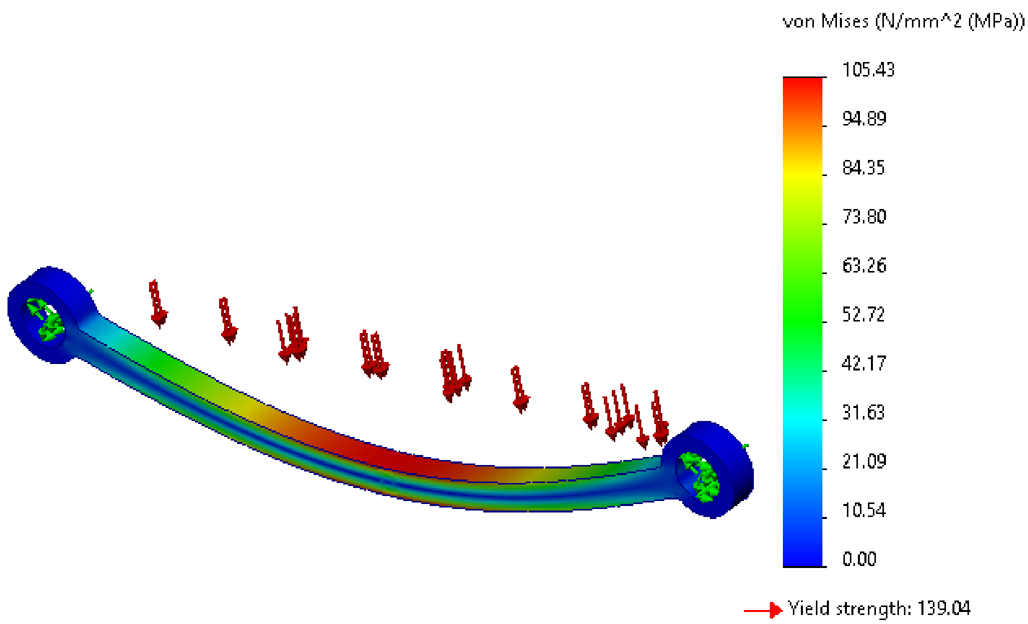

Figure 11: Link linear von Mises stress plot

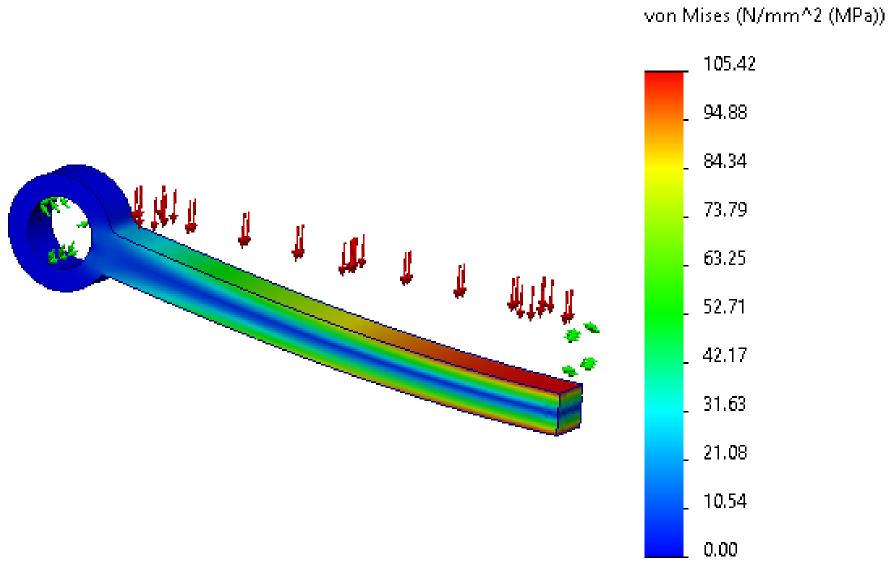


Figure 12: Half link linear von Mises stress plot

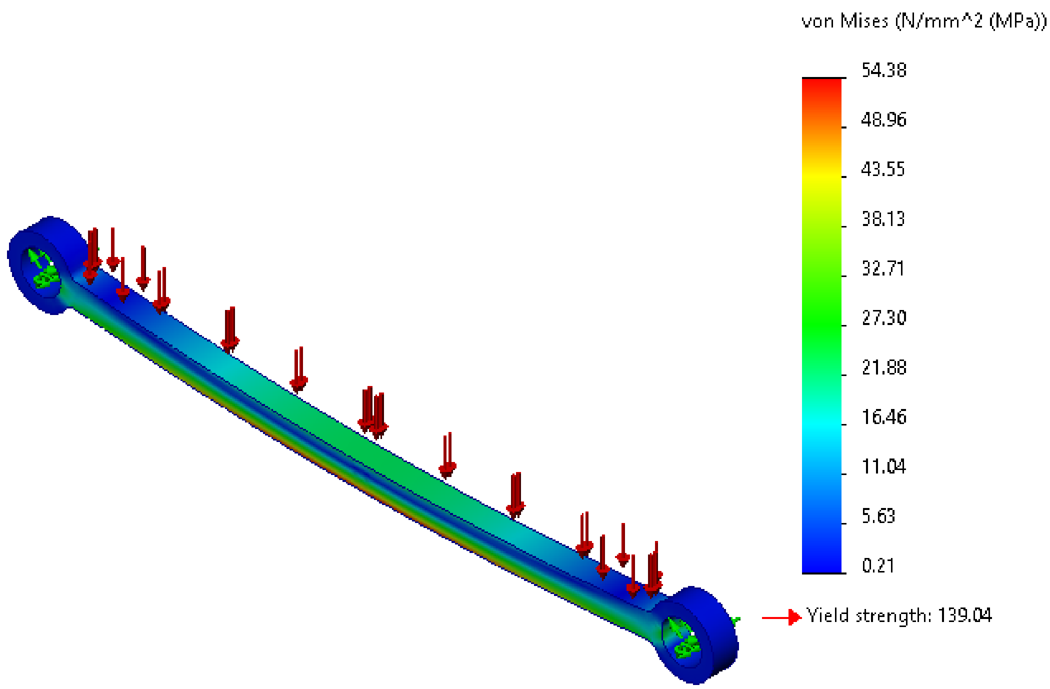


Figure 13: Link nonlinear von Mises stress plot

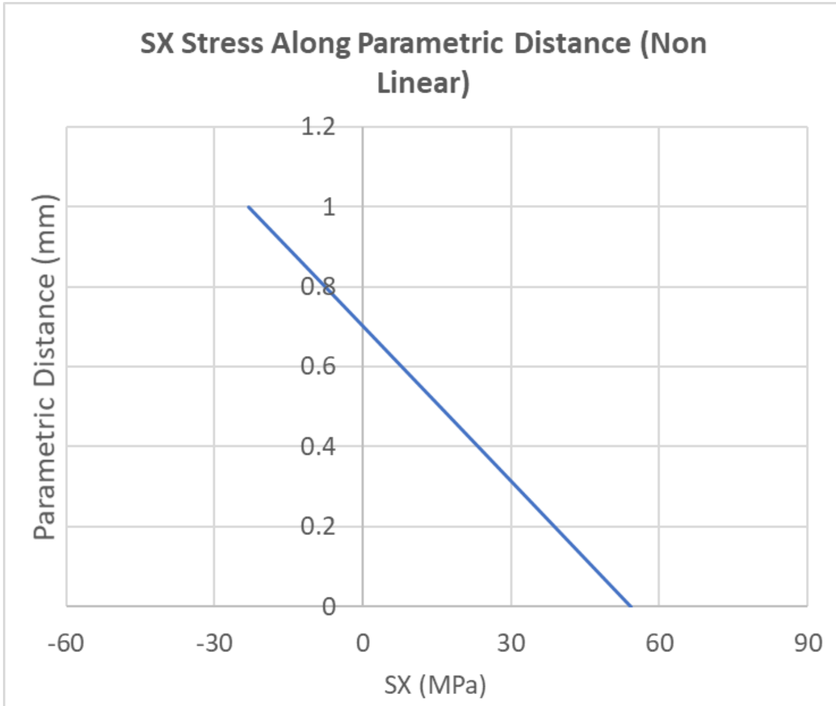


Figure 14: Normal stress along x axis plot over parametric distance for the non linear study of the link.

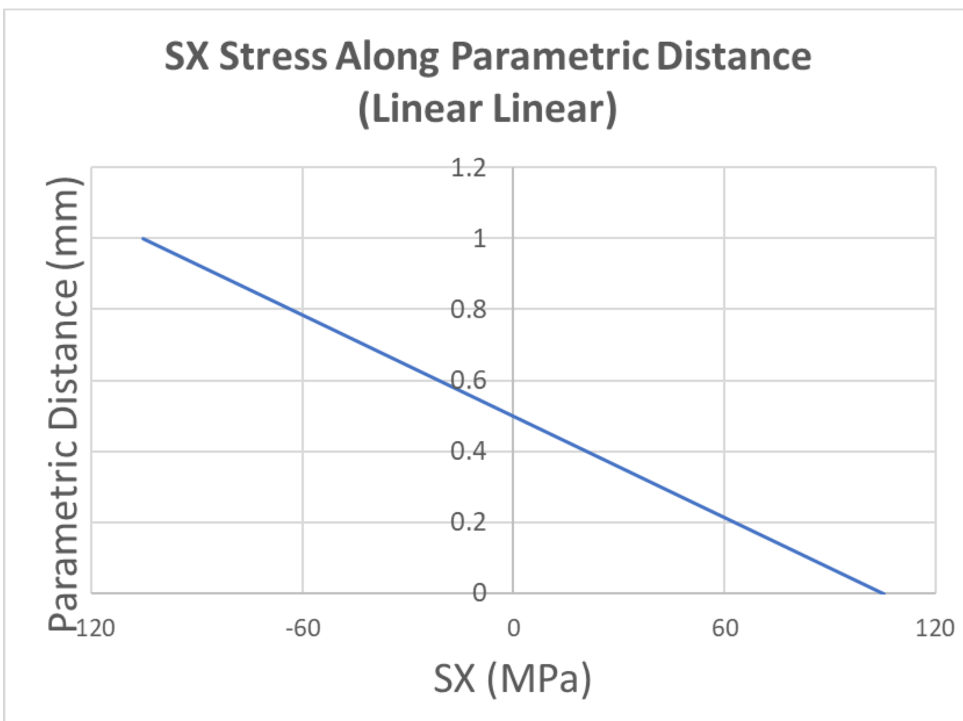


Figure 15: Normal stress along x axis plot over parametric distance for the linear study of the link.

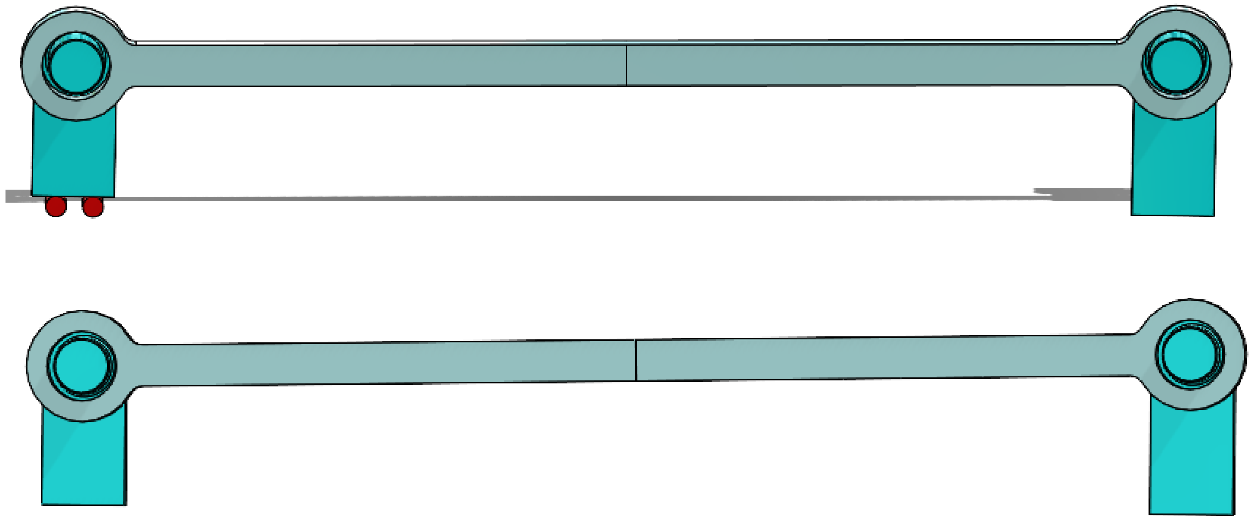

Figure 16: representation of the Non linear link fixtures (top) Linear link fixtures (bottom)

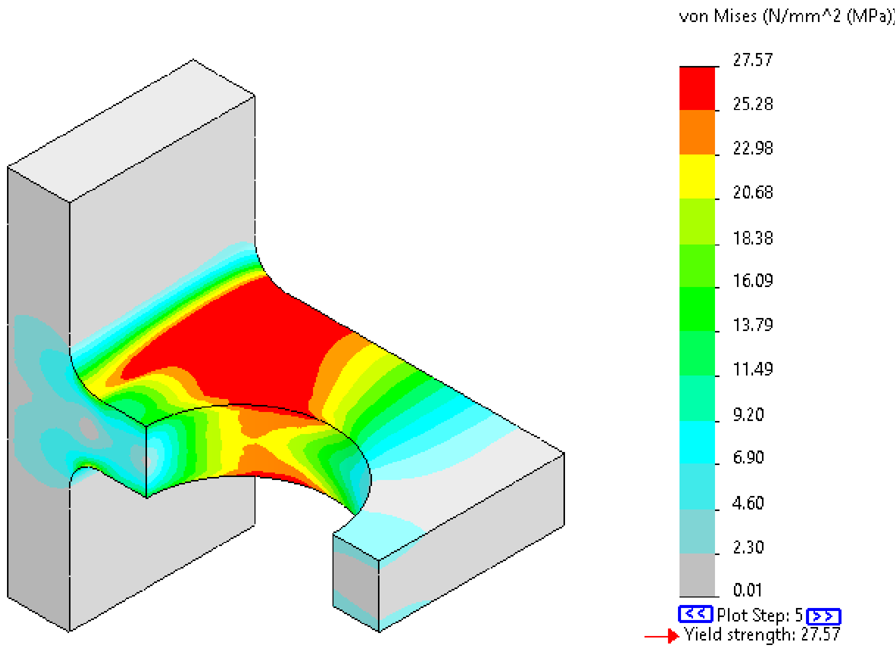


Figure 17: Bracket nonlinear von Mises stress plot at plot step 5 at maximum loading

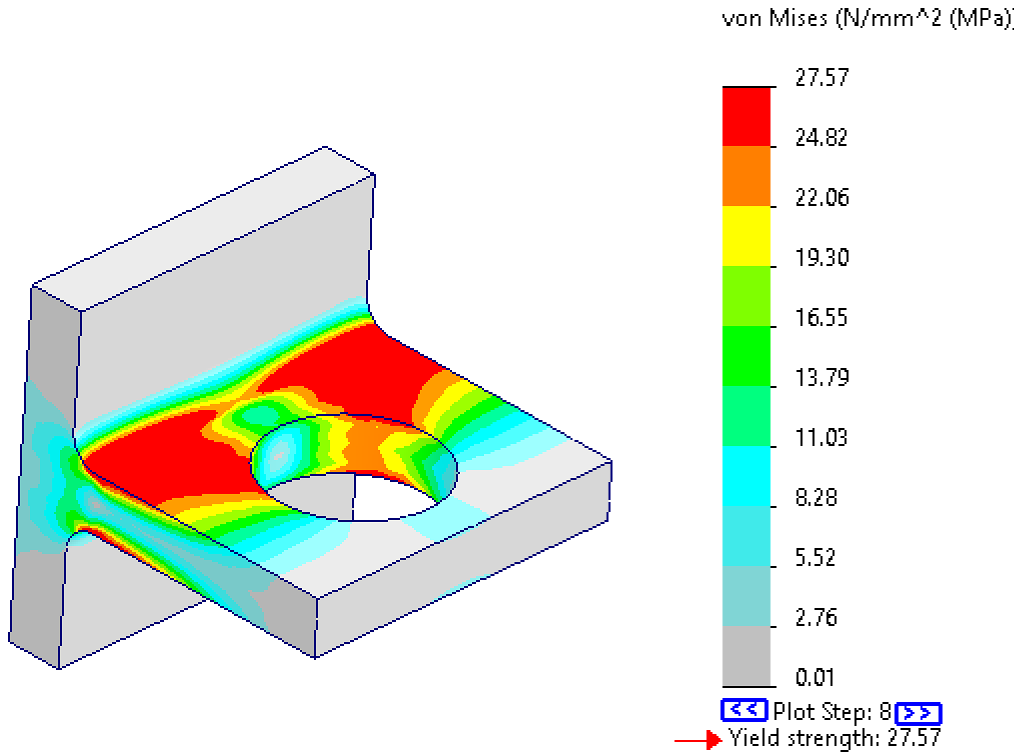


Figure 18: Full model bracket nonlinear von Mises stress plot at plot step 5 at maximum loading

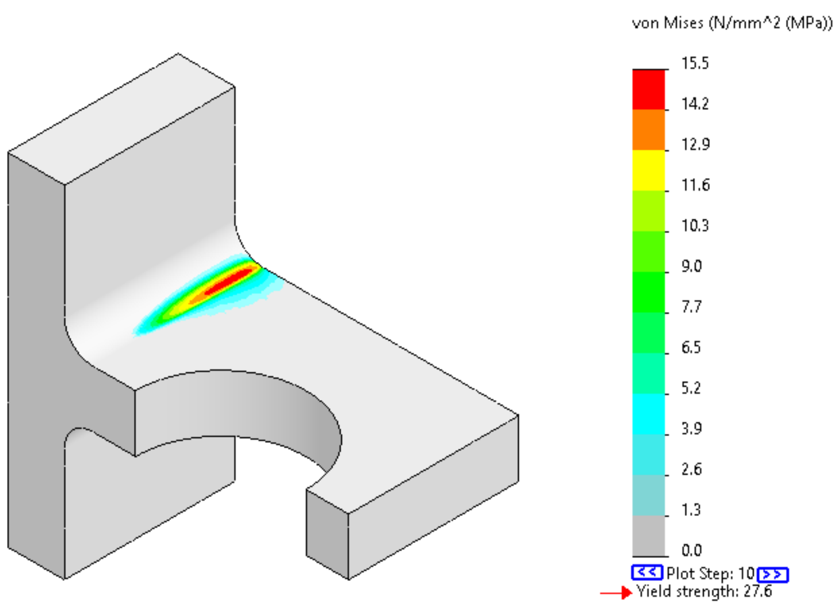

Figure 19: Bracket non linear residual stress at step 10 after load removal

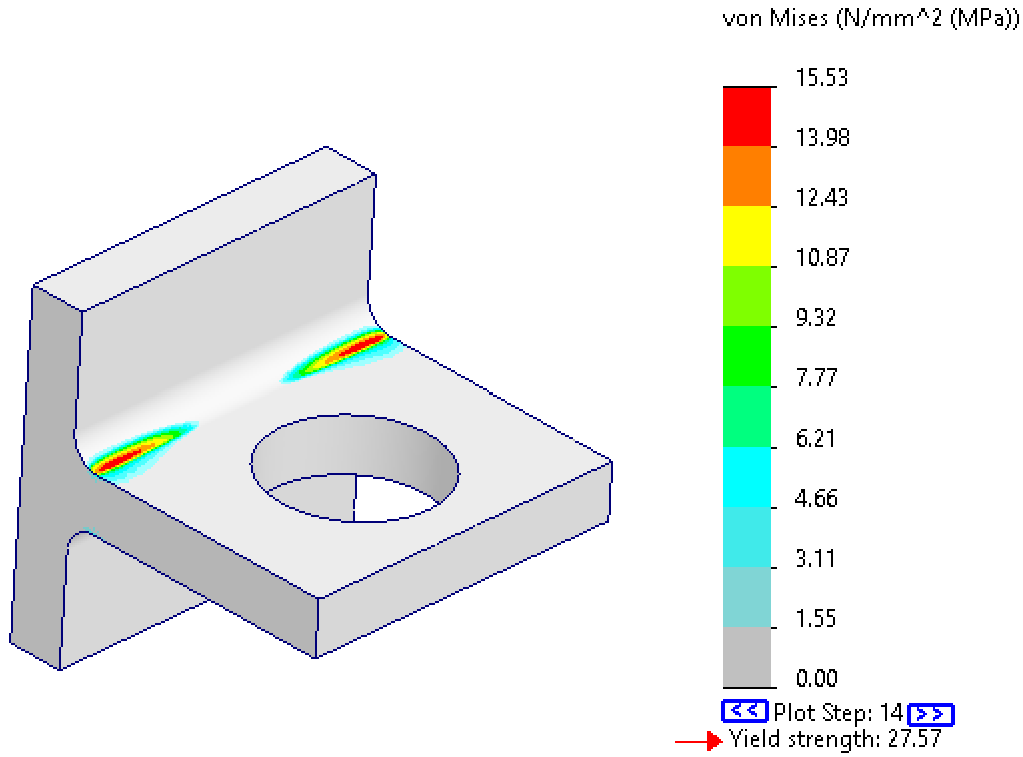


Figure 20: Full Model bracket non linear residual stress at step 10 after load removal

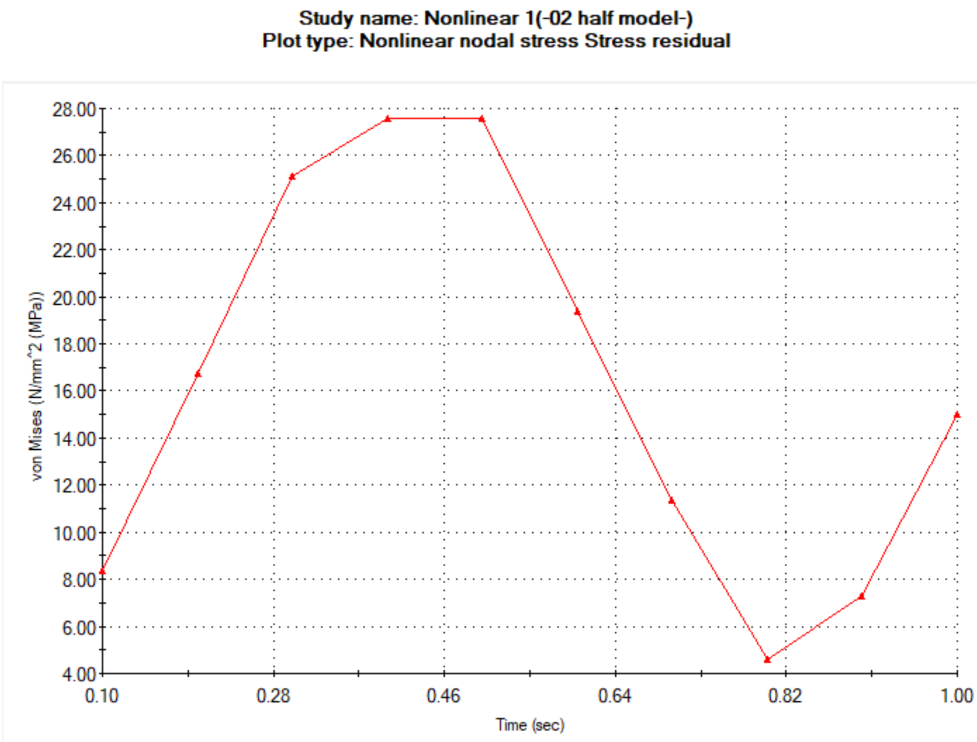


Figure 21: Bracket nonlinear step 10 plot von Mises response graph

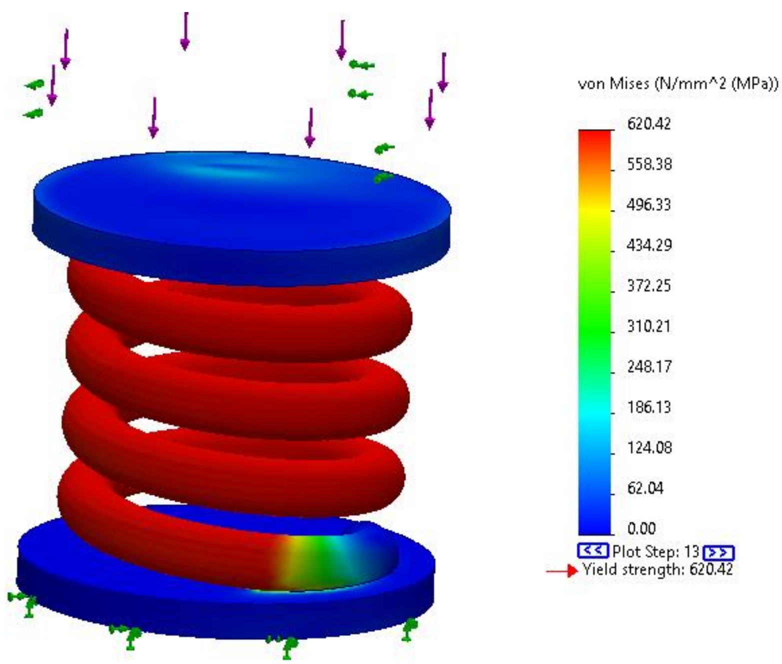


Figure 22: Spring nonlinear von Mises stress plot

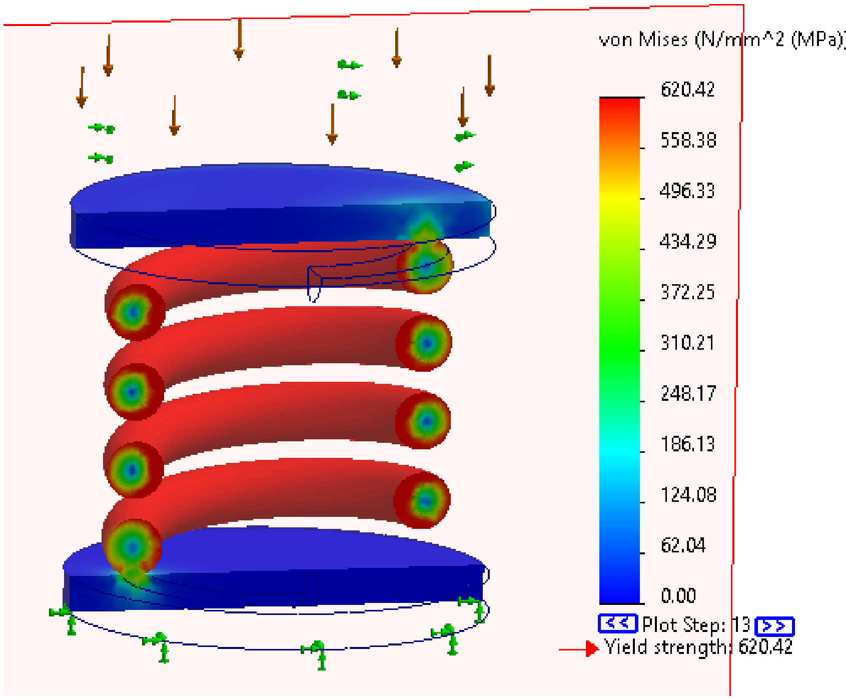


Figure 23: Sectional view of spring nonlinear von Mises stress plot

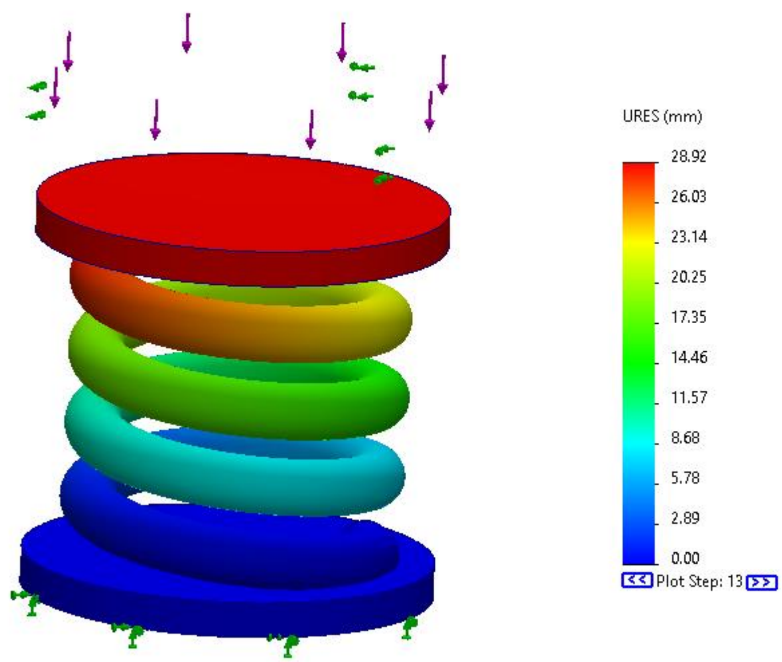


Figure 24: Spring nonlinear displacement plot

<table>
<tr><th>Model</th><th colspan="2">Max Stress Non-Linear (MPa)</th><th>Max Stress Linear (MPa)</th><th>Max Displacement Non linear (mm)</th><th>Max Displacement Linear (mm)</th></tr>
<tr><td rowspan="4">NL002</td><td>Top Shell</td><td>264.9</td><td rowspan="4"></td><td rowspan="4">311.6</td><td rowspan="4">348.2</td></tr>
<tr><td>Bottom Shell</td><td>282.2</td></tr>
<tr><td>P1 Stress bottom</td><td>283.5</td></tr>
<tr><td>P3 Stress top</td><td>-263.1</td></tr>
<tr><td>Clip</td><td colspan="2">57.9</td><td>91.993</td><td></td><td></td></tr>
<tr><td>Round Plate</td><td colspan="2"></td><td></td><td>5.31</td><td>8.56</td></tr>
<tr><td>Curved Plate</td><td colspan="2"></td><td></td><td>0.87</td><td>0.97</td></tr>
<tr><td>Link</td><td colspan="2">54.38</td><td>105.43</td><td></td><td></td></tr>
<tr><td rowspan="2">Bracket</td><td>Max Loading</td><td>27.57</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Residual stress</td><td>15.5</td></tr>
<tr><td>Spring</td><td colspan="2">620.42</td><td></td><td></td><td>28.92</td></tr>
</table>

Figure 25: Tabulated results of stresses and displacements of linear and nonlinear models done in this lab.

### Discussion and Interpretation of Results

Large displacement can be seen as one of the sources of nonlinearity as seen in figures 1-15. Such cases can be modeled with static studies as accounting for large displacement can be seen to accurately account for the nonlinear sources. However, the displacement models cannot be accurately modeled as only nonlinear studies can fully capture the following deformation as seen in figure 4. Comparing the distributions of stress in figures 2, it is evident that the nonlinearity has caused an unsymmetric pattern of stress distributions, thus needing to account for change over a period of time. In such case with the bracket, it can be seen in figures 17 that the load would peak at step 5 and drop thereafter. Load variation cannot be accurately carried out without accounting for the large displacements.

Total deformation may not always be indicative of experiencing nonlinearity in a model. From the round plats, though they do not experience as many deformations (figure 7) with maximum displacement only reaching below 10 mm as opposed to figures 1, with deformation above 300 mm, the linear model was not able to capture the reduction of displacement, with error around 61%. As seen with the curved round plates, where error can be seen to only reach 11 %, geometry is a stronger indication of nonlinearity.

Nonlinear solutions provide a way of accounting for the tensile stress due to the capturing of restraints displacement otherwise neglected. From figures 11 and 13, the linear solutions showed a symmetric varying stress distribution as opposed to the nonlinear showing variations. The tensile stress accounts for the change in the load distribution and causes an overall different stress profile as seen in figures 14 and 15. Such nonlinear cases can cause axial load from fixtures represented in figure 16.

Figures 16-24 represent how material may cause nonlinearity. Both models were set to when the material are in the plastic region and no longer governed by the elastic modulus. Time dependance is one of the parameters introduced. Though different materials are used, with different yield strength, both model displays the trend of nonlinearity once above yielding values are reached

## Conclusions

Nonlinearity caused by large displacements, initial conditions and materials discredits results obtained by linear solutions. Variation may occur to the stiffness as linear solution do not consider change over time and therefore only provide one solution iterations. Geometry changes can be seen to be an important factor as well as yield strength becoming an important factor to determine the need for nonlinear solutions.

## References

[1] Engineering Analysis with SolidWorks Simulation 2024, by Paul Kurowski (2024), ISBN-10: 1630576298.
[2] A First Course in the Finite Element Method, Enhanced Edition, 6th Ed., by Daryl Logan (2022), ISBN-10: 0357884140.
[3] Finite element simulation: A user's perspective, Chris V. Nielson (2021), https://doi.org/10.1016/B978-0-323-85255-5.00011-X.