Computational Mechanics Tools
Abaqus Nonlinear Analysis

Assignment 4

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1 Introduction

Traditionally, linear elastic analysis has been widely used in structural engineering, due to the wide variety of problems which may be accurately modeled within this framework. Nonetheless, since linear models are based on infinitesimal strains and linear material behavior, they are not suitable for the modelling of certain phenomena such as buckling, plastic behavior, or fracture, to mention a few.
Modern computers have allowed non-linear models to become a part of everyday engineering analysis, making it possible to accurately solve problems that could not be successfully solved through linear analysis. Nowadays, commercial codes such as Abaqus or ANSYS are commonly used in industry for the solution of this kind of problems.

2 Problem Description

The assignment consists of performing a non-linear analysis of two different structures, based on the Abaqus tutorials provided at the CIMNE Virtual Center.

NOTE: Since the tutorial was followed in its entirety, the model creation will not be presented, as this report is only focused on discussing the analysis results.

1. The first structure is a steel plate with a hole on it, being submitted to axial tensile force. At first, the material is only given elastic properties (E=2.1e5 MPa, v=0.25), hence performing a linear analysis. Afterwards, plastic properties are added in order to obtain a non-linear behavior. The main tasks in the analysis are:

   - Plot the distribution of Von Mises stresses in the plate.
   - Plot the force-displacement curve at the point-set (point-set indicated in tutorial).
   - Add the plastic properties and compare the results. Discuss the differences in the force-displacement curve for the three different cases.

   The material properties for the plate are:

Case	fy1 (MPa)	Plastic Strain 1	fy2 (MPa)	Plastic Strain 2
Isotropic, perfectly plastic (A)	460	-	-	-
Isotropic, plastic B	460	0	520	5e-3
Isotropic, plastic C	460	0	520	2e-3

Table 1: Plate Material Non-linear Properties, Plate Model

2. The second model is the contact between a fixed pin and a plate, which is pulled at one of its ends. Taking advantage of the symmetry of the structure, only the upper half of the pin and the plate are modelled. Following the tutorial, the main tasks are:

   - Plot the distribution of Von Mises stresses on the deformed shape with an amplification factor of 10. Set the scale of stresses between 0-460 Mpa and make it so that the stresses over this limit are plotted in dark red.
   - Plot the force displacement curve for the horizontal reaction at the point-set (point-set indicated in tutorial).

- Add the plastic properties to the two materials, the same ones as in the previous model for the plate, and different ones for the pin. Compare the results with the elastic case.

Case	fy1 (MPa)	Plastic Strain 1	fy2 (MPa)	Plastic Strain 2
Isotropic, plastic	460	0	520	5e-3

Table 2: Plate Material Non-linear Properties, Pin-Plate Model

Case	fy1 (MPa)	Plastic Strain 1	fy2 (MPa)	Plastic Strain 2
Isotropic, plastic A	900	0	1000	2e-3
Isotropic, plastic B	320	0	400	5e-3

Table 3: Pin Material Non-linear Properties, Pin-Plate Model

3 Results

3.1 Plate Model

For the first model, four different analysis were performed, each one of them corresponding to different mechanical properties for the material of the plate (Table 1). The following results were obtained.

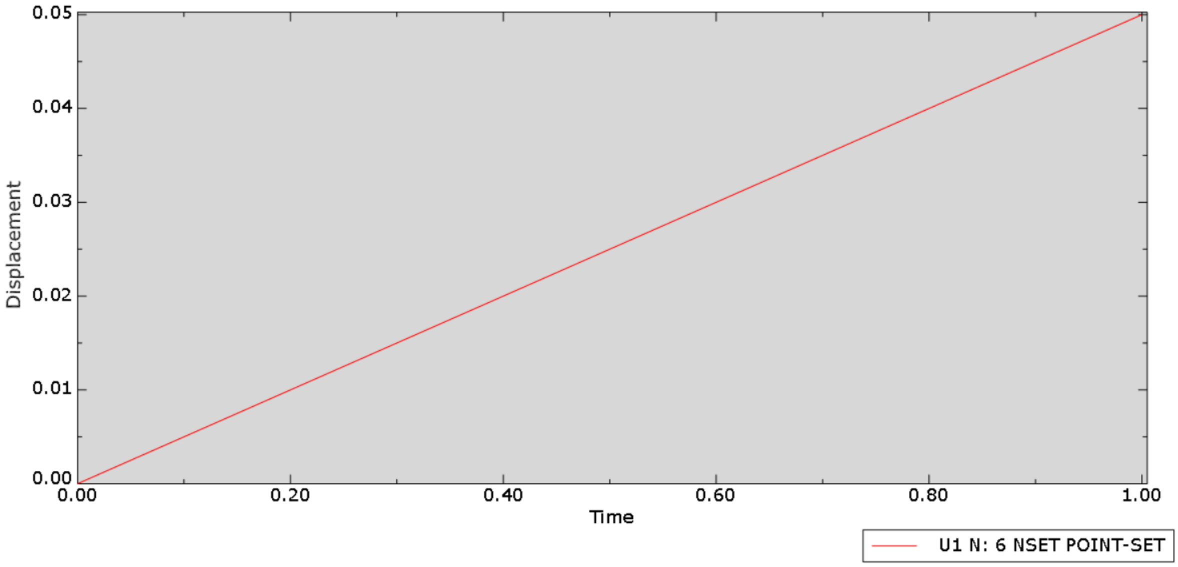

Figure 1: Time vs. Displacement at Point Set, Plate Model

The displacement-time curve is the same for all four analysis. The prescribed displacements are applied to the structure at a constant rate throughout the analysis time interval, and therefore a force-displacement curve would exhibit the same behavior as a force-time curve. For simplicity purposes, the force-time curve was plotted instead of the force-displacement curve for the analysis of the results.

3.1.1 Elastic Behavior

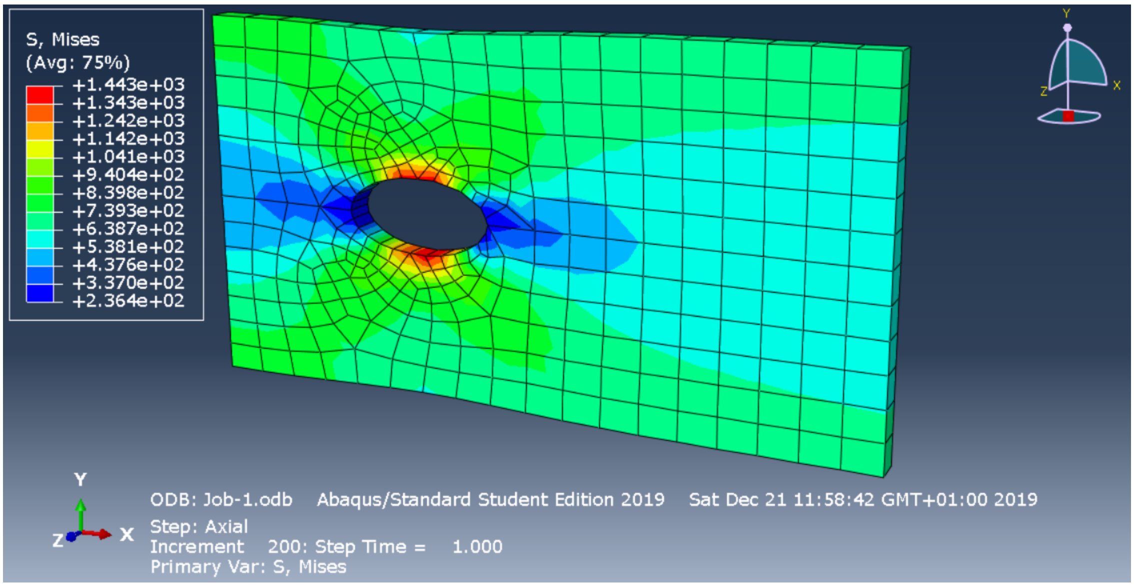

Figure 2: Von Mises Stress, Elastic Plate Model

For the elastic analysis, the maximum Von Mises stresses are concentrated around the hole on the plate, with a magnitude of approximately 1400 MPa, which widely exceeds the yield stress of any commercial steel. Despite the non-symmetric location of the hole, the stresses around it exhibit a symmetric distribution, but lose symmetry as distance to the hole increases.

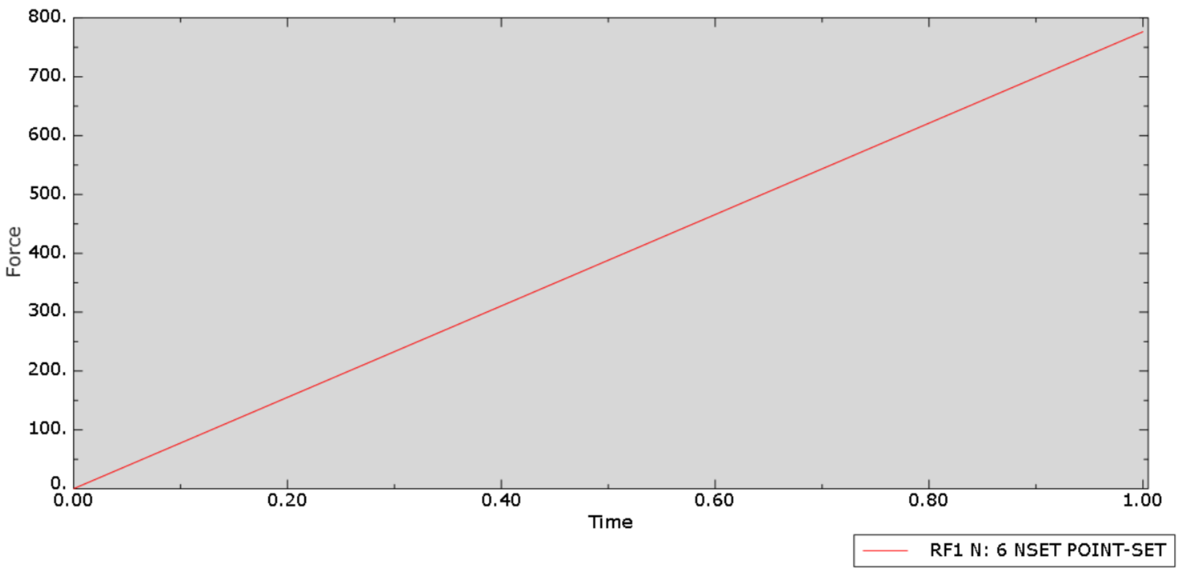

Figure 3: Force-Displacement Curve, Elastic Plate Model

As expected, the plate has a linear response to the applied displacements. Force increases at a constant rate.

3.1.2 Perfectly Plastic Behavior (A)

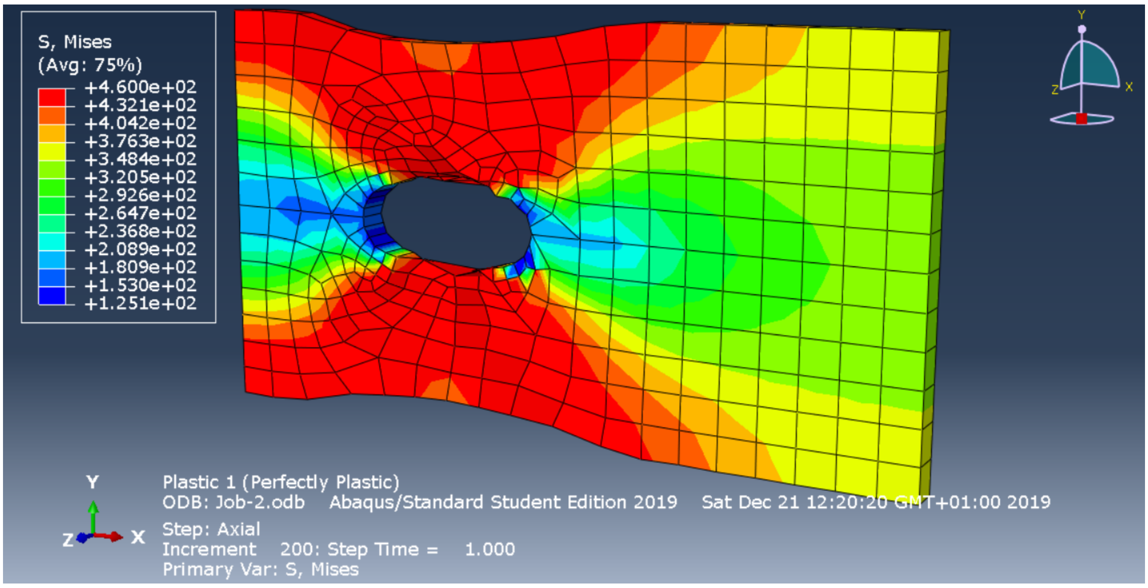

Figure 4: Von Mises Stress, Perfectly Plastic Plate Model (A)

The largest stresses are still concentrated around the hole. Plastic strains (non-linear behavior) are presented in large areas surrounding the hole, as the yield stress of the material (460 MPa) has been reached. Deformation is visibly higher than in the elastic model, since they are plotted with the same scale factor.

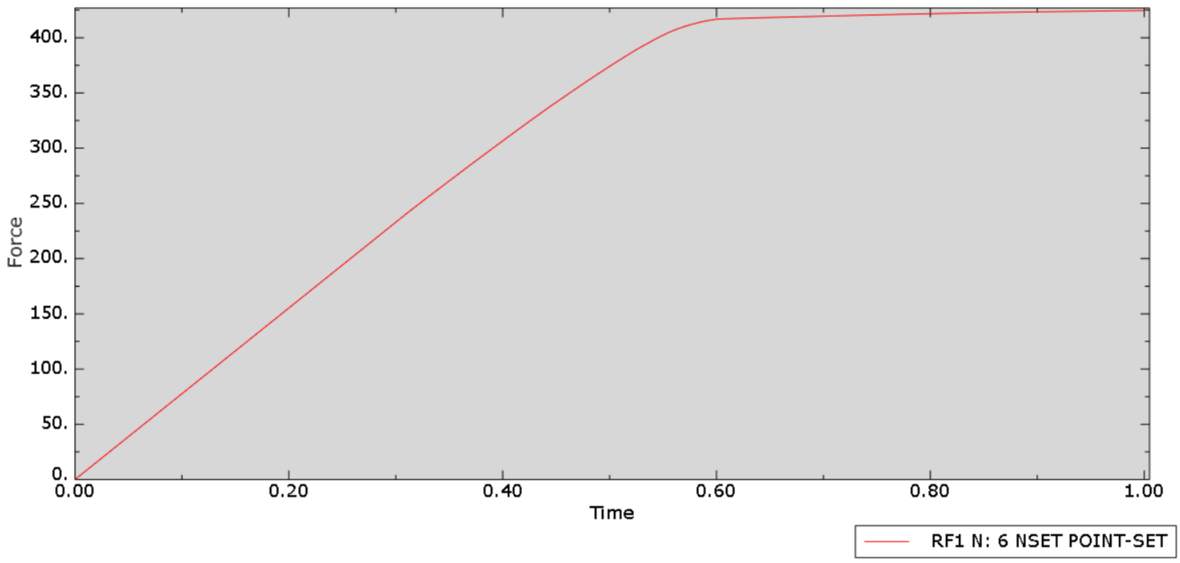

Figure 5: Force-Displacement Curve, Perfectly Plastic Plate Model (A)

The curve becomes practically horizontal as the yield stress is reached, exhibiting a perfectly plastic behavior of the structure with no hardening, as expected.

3.1.3 Plastic Behavior B

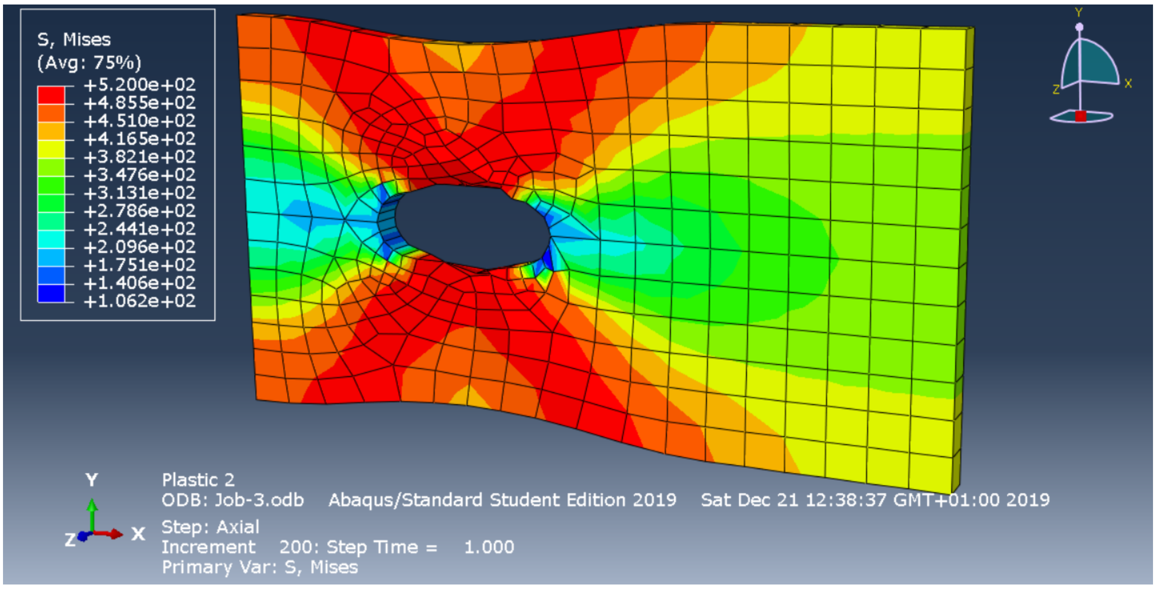

Figure 6: Von Mises Stress, Plastic Plate Model B

For case B, the same area of the plate which exceeded the yield stress in the perfectly plastic case, also exceeds the yield stress in this analysis. Nonetheless, not the entire area which reached plastic behavior also reached the stress required to achieve the final phase of plasticity for the material. Also, the maximum stress present is higher than in the previous case due to hardening of the material.

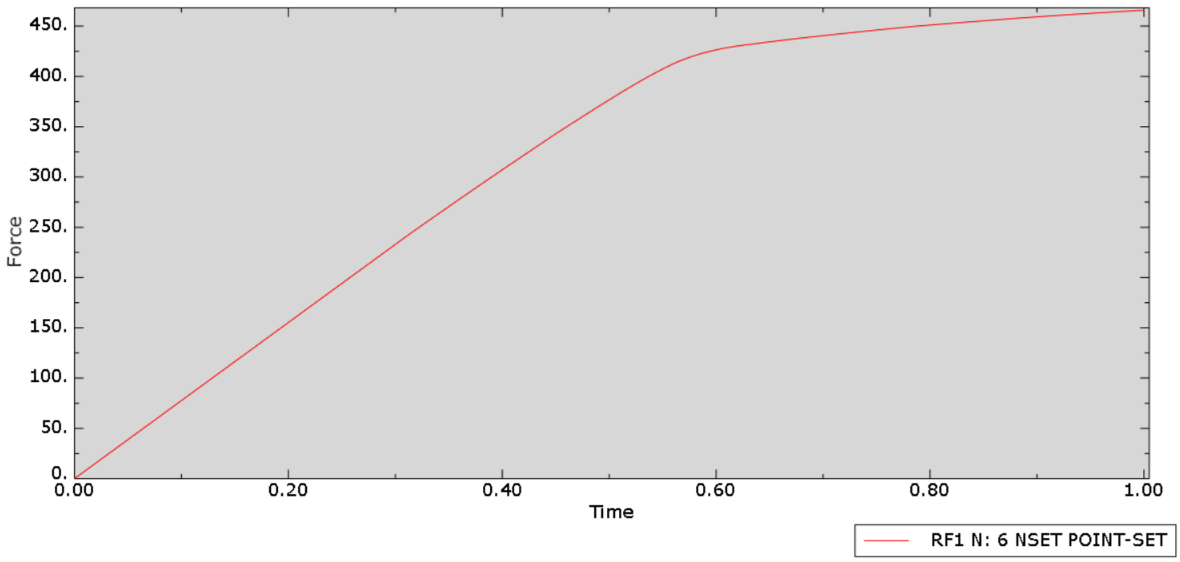

Figure 7: Force-Displacement Curve, Plastic Plate Model B

The slope of the curve in the plastic range is positive and not horizontal like in the previous case, which implies the existence of a certain degree of hardening to due deformation of the material.

3.1.4 Plastic Behavior C

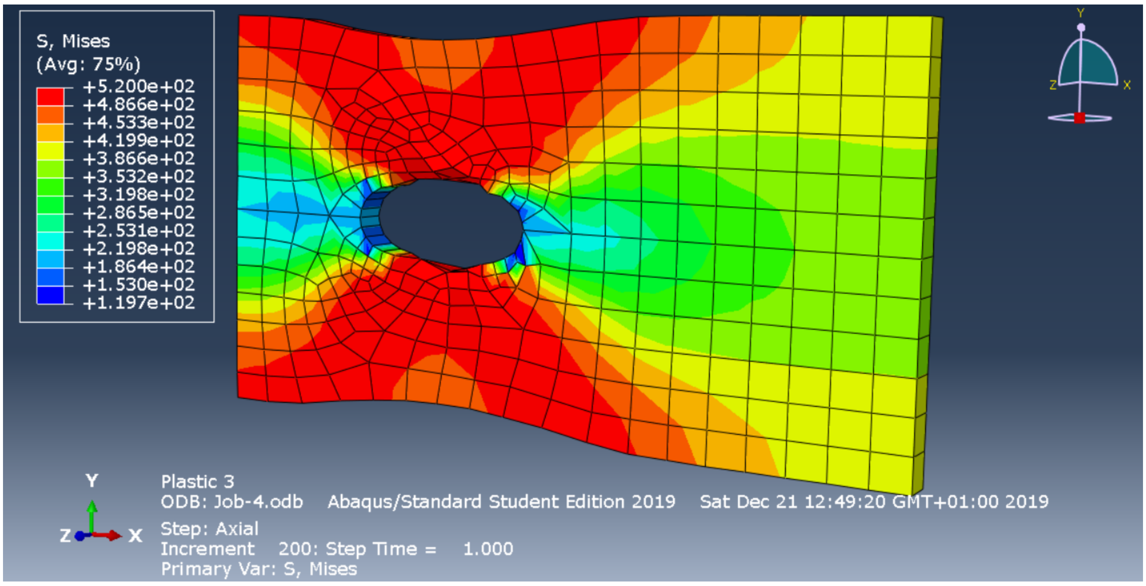

Figure 8: Von Mises Stress, Plastic Plate Model C

The same area of the plate exceeded the yield stress of the material as in the previous two cases. Nonetheless, a larger area exceeded stresses of 520 MPa than in the previous case, due to the smaller strain (2e-3) associated to this stress in the plastic properties of the material, when compared to case B (5e-3).

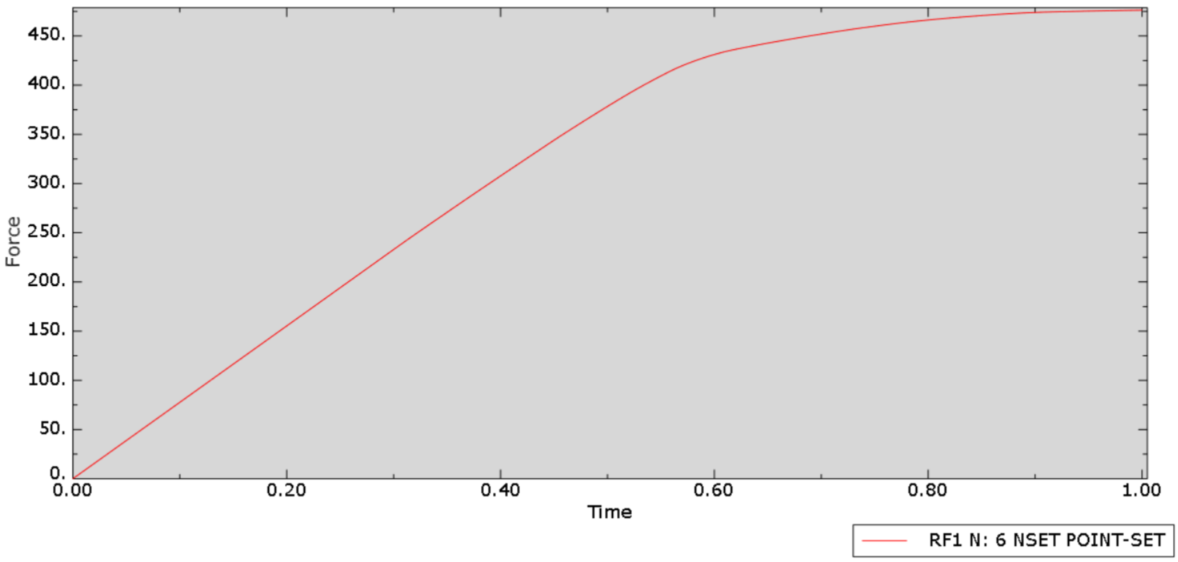

Figure 9: Force-Displacement Curve, Plastic Plate Model C

The strain range for the plastic stage of the material is the same as in case B. However, the slope of the curve changes at a higher rate in this case, since it is initially higher and decreases as strain increases.

3.2 Pin-Plate Model

For the pin-plate model, three analysis were performed. The first one corresponds to a linear model, while the remaining two correspond to non-linear models, varying the mechanical properties of the pin (Table 3) while maintaining the properties of the plate constant (Table 2).

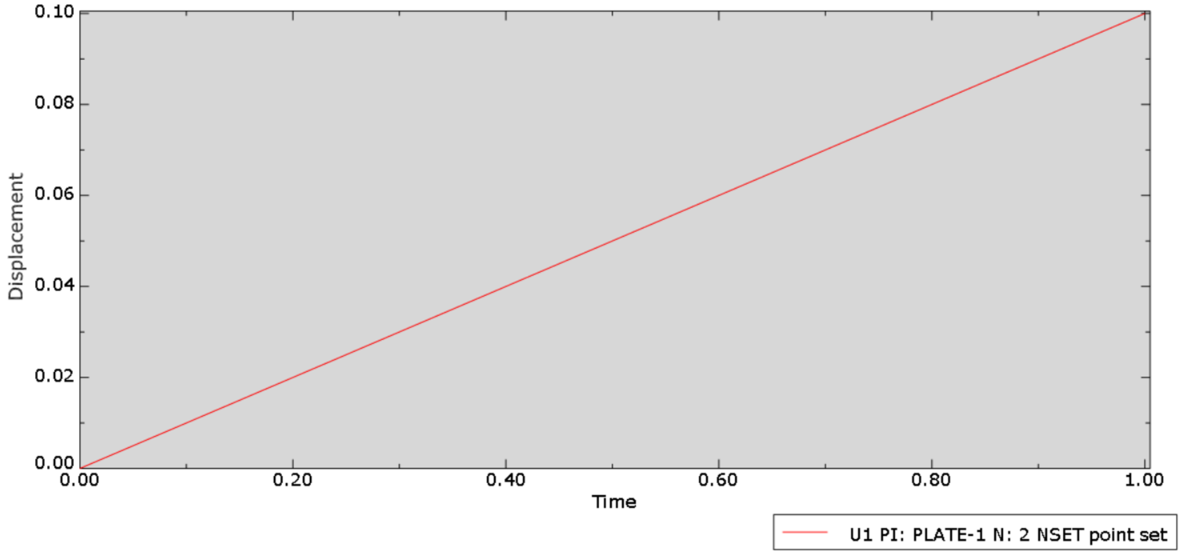

Figure 10: Time vs. Displacement at Point Set, Pin-Plate Model

Just like in the plate model, the displacement-time curve is linear for all cases due to the fact that the displacements are applied at a constant rate throughout the analysis time interval. This allows us to plot force-time curves instead of force-displacement curves since they will exhibit the same behavior.

3.2.1 Elastic Behavior

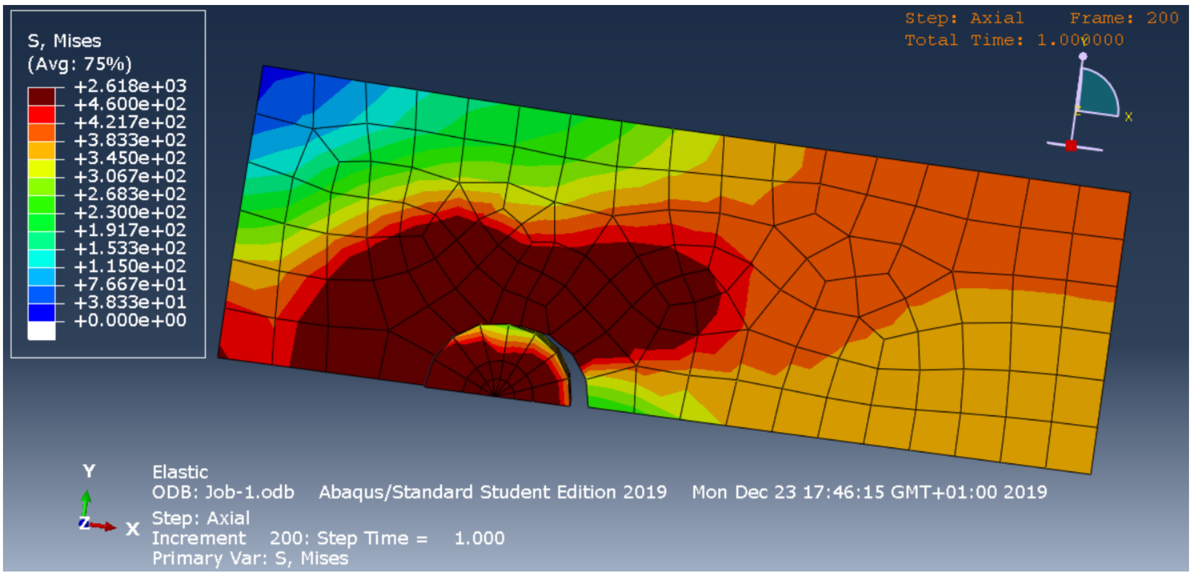

Figure 11: Von Mises Stress, Elastic Pin-Plate Model

For the elastic model, both the plate and the pin are subjected to stresses of similar magnitude, with a maximum stress of approximately 2600 MPa (almost twice the maximum stress present in the elastic plate model). The largest stresses are present around the area of contact between the pin and the plate.

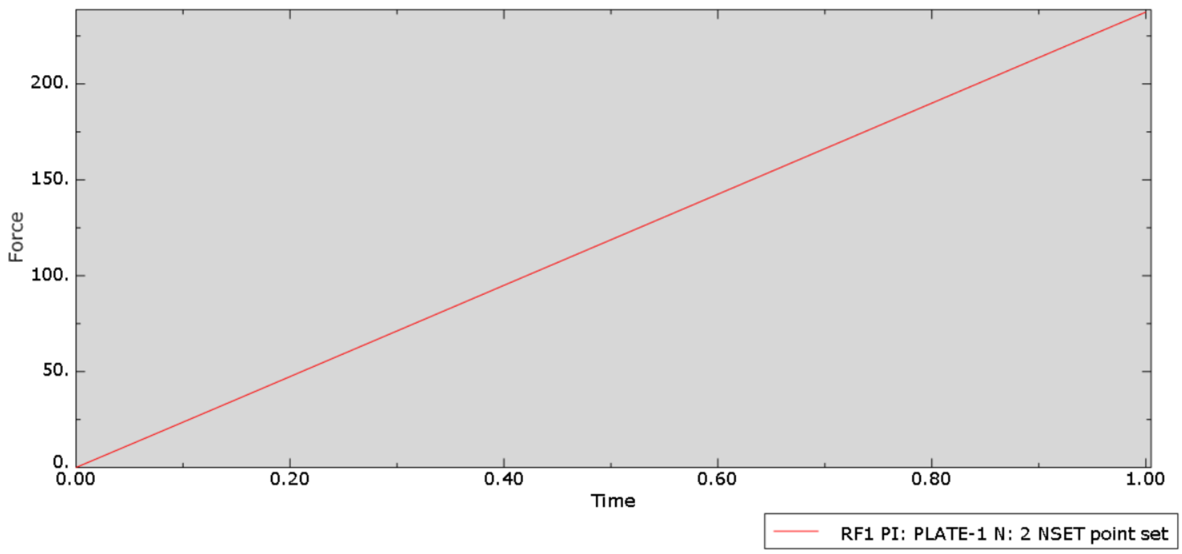

Figure 12: Force-Displacement Curve, Elastic Pin-Plate Model

As expected, the behavior of the structure is linear throughout the loading time interval.

3.2.2 Plastic Behavior A (Pin Strength > Plate Strength)

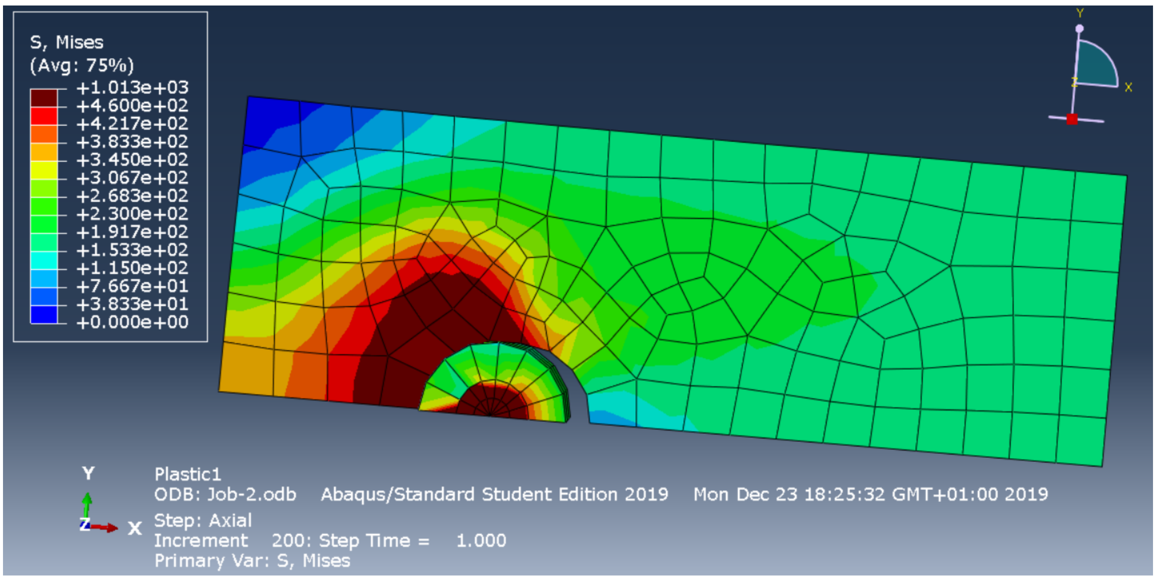

Figure 13: Von Mises Stress, Plastic Pin-Plate Model A

In this case, both the pin and the plate reach plastic behavior since the yield stress of both materials is exceeded. The largest stresses (and therefore strains) on the plate are present around the area of contact with the pin, while the stresses in the pin concentrate around its restrained point. The structure is clearly more deformed than it was in the elastic model. It is worth noting that the color distribution on the plate is not accurate, since the scale is distorted by the strength assigned to the pin material, which is considerably higher than the one assigned to the plate material. This means that the stresses on the plate are actually lower than the ones depicted in the area of the darkest red color in the graphic.

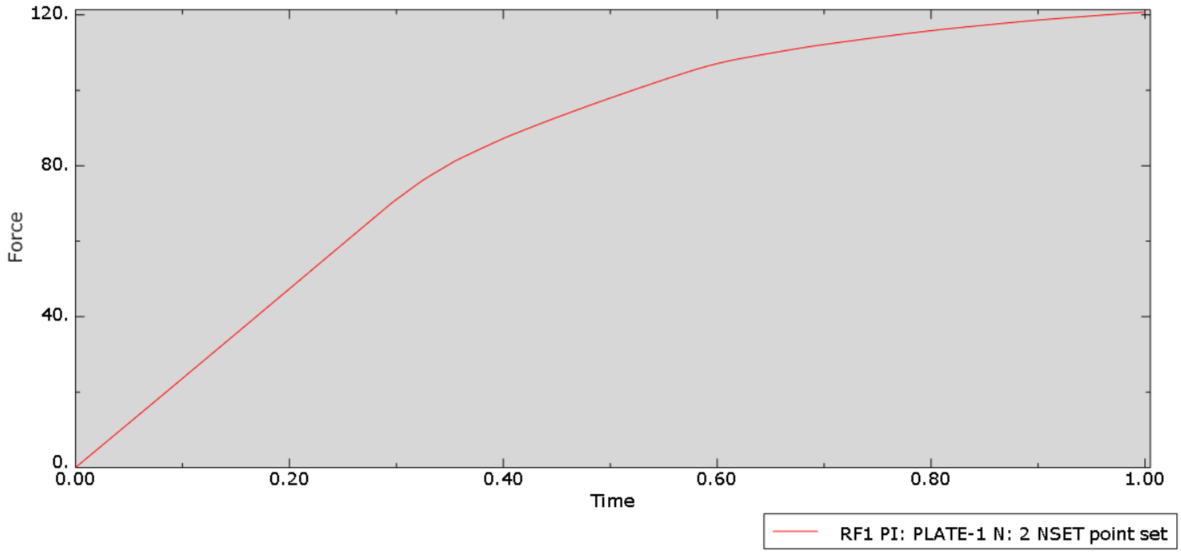

Figure 14: Force-Displacement Curve, Plastic Pin-Plate Model A

There are two clear slope changes in the force-displacement curve, each one of them corresponding to the displacement at which the plate and the pin start presenting plastic deformations, respectively.

3.2.3 Plastic Behavior B (Pin Strength < Plate Strength)

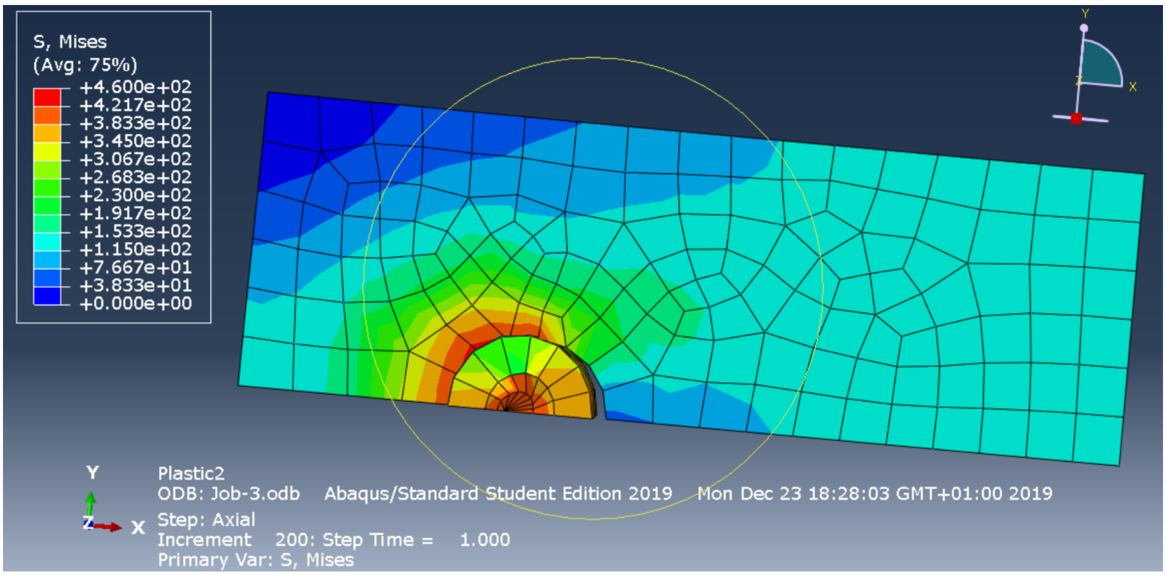

Figure 15: Von Mises Stress, Plastic Pin-Plate Model B

Since the strength of the pin is lower than the strength of the plate, the stresses on the plate remain below its yield stress while the stresses on the pin exceed it. The deformations on the plate are much lower than in the previous cases, since the displacements are being accounted for with pin deformation.

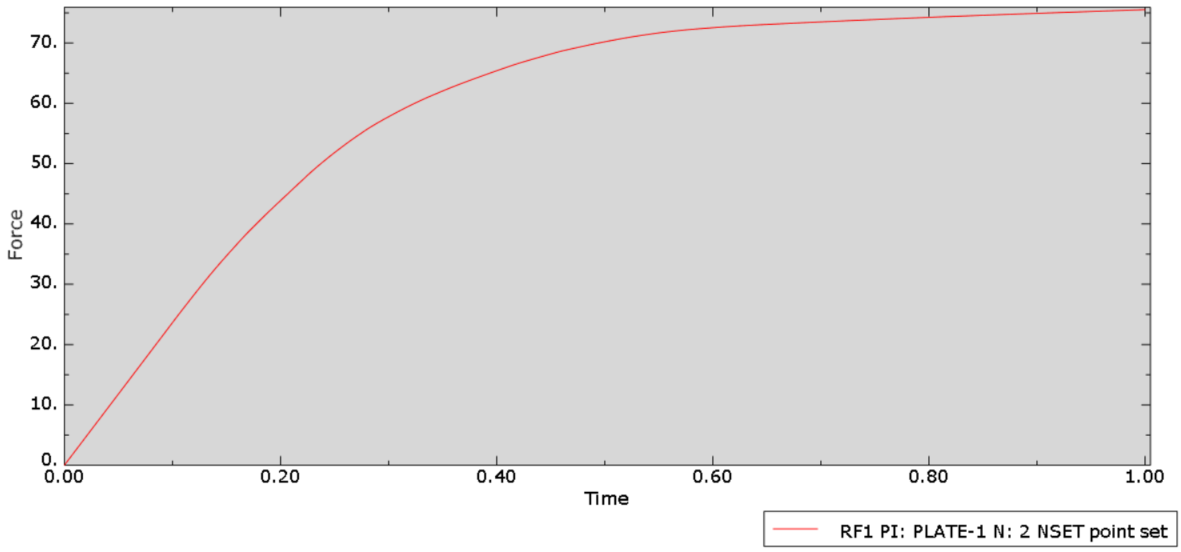

Figure 16: Force-Displacement Curve, Plastic Pin-Plate Model B

The pin reaches plastic behavior early on in the analysis (0.20 s) and continues to deform while the plate only serves to transmit the load to the pin while remaining elastic.

4 Conclusions

- For both models, changing the materials' mechanical properties changed the behavior of the structure dramatically. Making an accurate selection of the material properties introduced into a computational structural analysis can mean the difference between a useful model that makes accurate predictions of the behavior of a structure and a model which will not represent the real behavior of the structure it is supposed to simulate.
- The maximum stresses present in both structures for the linear analysis (no plastic properties added to the materials) are much larger than the strength of any steel commercially available nowadays. Taking into account the fact that both structures are supposed to be made of steel, this means that the elastic models do not reflect the real behavior of the simulated structures. This is a perfect example of a situation in which linear analysis is not a sufficient tool and non-linearity is necessary to construct a model that can provide accurate results.