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Lennart Börgesson, Jan Hernelind			2013-12-17	

4.1 Analysis of how a buffer with brittle shear properties may affect the rock shear case

Lennart Börgesson
Clay Technology AB

Jan Hernelind
5T Engineering AB

Table of Contents

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel and Waste Management Co
PO Box 250, SE-101 24 Stockholm
Visiting address Blekholmstorget 30
Phone +46-8-459 84 00 Fax +46-8-579 386 10
www.skb.se
556175-2014 Seat Stockholm

1. Introduction

Tests on bentonite that has been affected by high temperatures have shown tendencies of brittle failure during shear in contrast to unaffected bentonite, which has smooth or no decrease in strength after peak shear stress. Figure 1 shows example of such results.

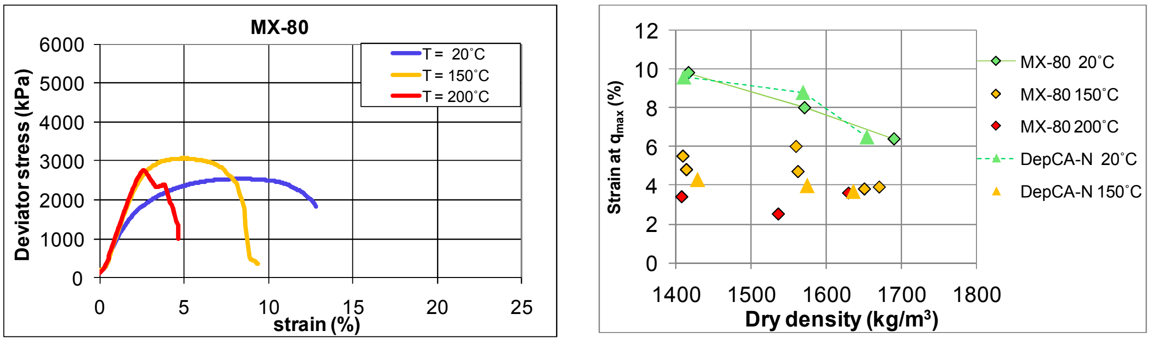


Figure 1. *Example of brittle failure. The left figure shows example of stress strain relations at uni-axial testing of specimen of bentonite that have been exposed to different temperatures. The right figure shows measured strain until failure as function of dry density for specimen exposed to different temperature.*

The general conclusions from the tests were that the shear strength is not affected but the failure may be brittle i.e. have an abrupt decrease in shear resistance after reaching maximum shear stress. Similar behaviour has been observed in field tests at temperatures below 100 °C (Dueck et al. 2011).

The effect of a rock shear through a deposition hole has been investigated with both laboratory tests that have been the bases for a material model of the buffer and by a large number of finite element calculations that have studied the effect of different rock shear cases on the stresses in the canister. The material models of the buffer and the copper and the calculation technique have been verified by modelling three laboratory tests of a rock shear scaled 1:10. These studies are reported in several technical reports and articles. See e.g. Dueck et al. (2010), Börgesson et al. (2010), Börgesson and Hernelind (2010) Hernelind (2010), Dueck (2010).

The influence of having a buffer that show brittle failure on the stresses in the canister after a rock shear has been studied with a series of finite element calculations.

2. Finite element model

The material model of the bentonite is the same as used in the referred documents. The bentonite is modelled as an elastic-plastic material with strain rate dependant stress-strain relations. Four different calculations have been done, one reference calculation with unaltered bentonite, two calculations with brittle bentonite and a fourth calculation with brittle bentonite and with the shear plane of the buffer removed in order to simulate that the shear strength has been completely lost in that zone. The material model for the reference case is identical to the material model of the bentonite used for SR-Site. The model is described in Börgesson et al. (2010).

Figure 2 shows the stress-strain relations for the models.

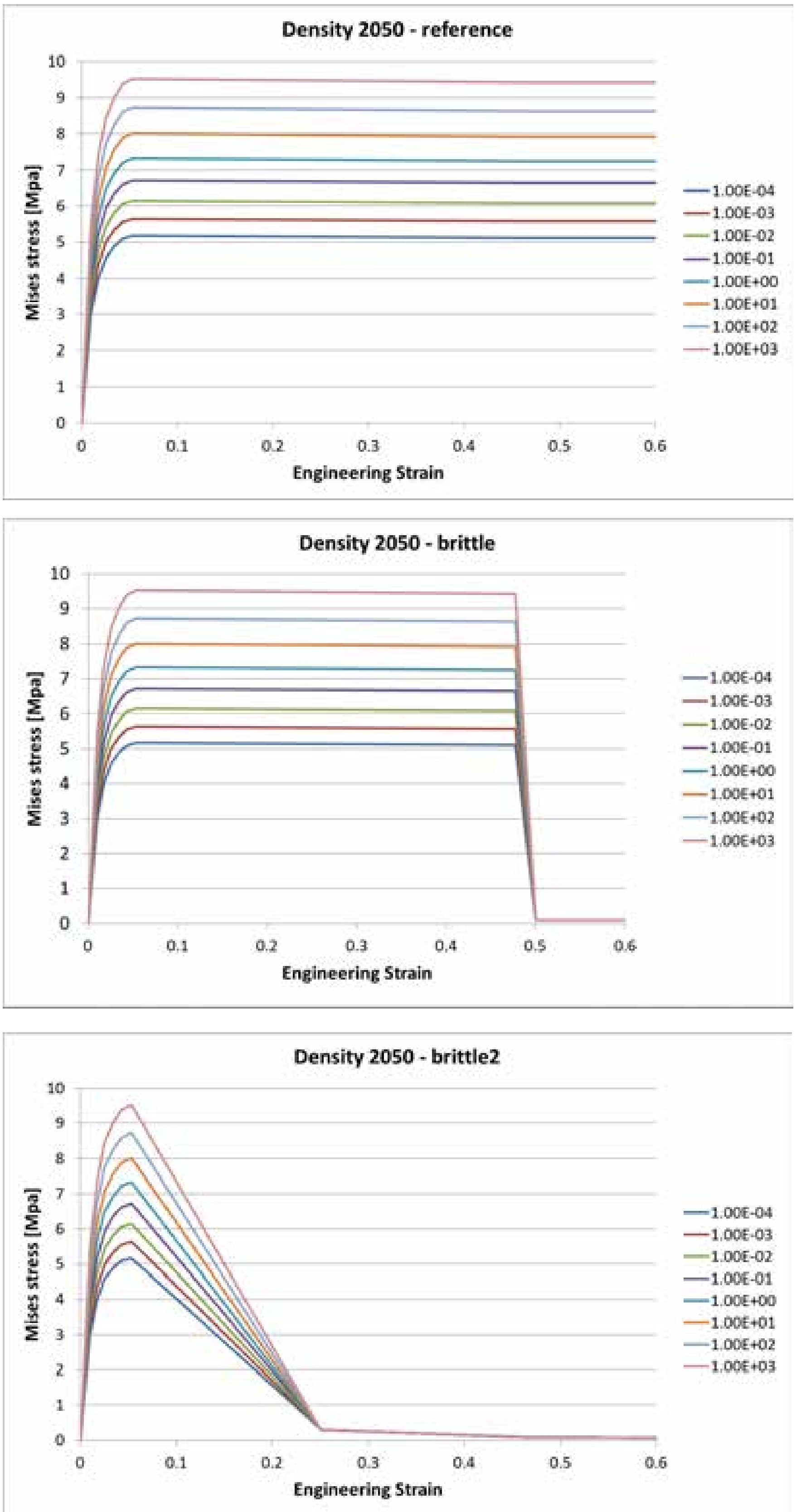


Figure 2. *Stress-strain relations of the bentonite in the calculations – see Table 1.*

The geometry of the canister consists of the insert (made of iron), the insert lid (made of steel) and the copper shell surrounded by buffer material (bentonite). The geometry is based on CAD-geometries received from SKB, "Ritningsförteckning för kapselkomponenter" (SKBdoc 1203875) and should therefore correspond to the current design.

The copper and cast iron were modelled in an identical way as the calculations made for SR-Site. These models are in detail described in Hernelind (2010).

The finite element mesh with horizontal shear at the ¼ point of the canister was used for the calculations since this case had proved to be the most critical that yields the highest stresses in the canister. The mesh is described in Hernelind (2010) and shown in Figures 3, 4 and 5.

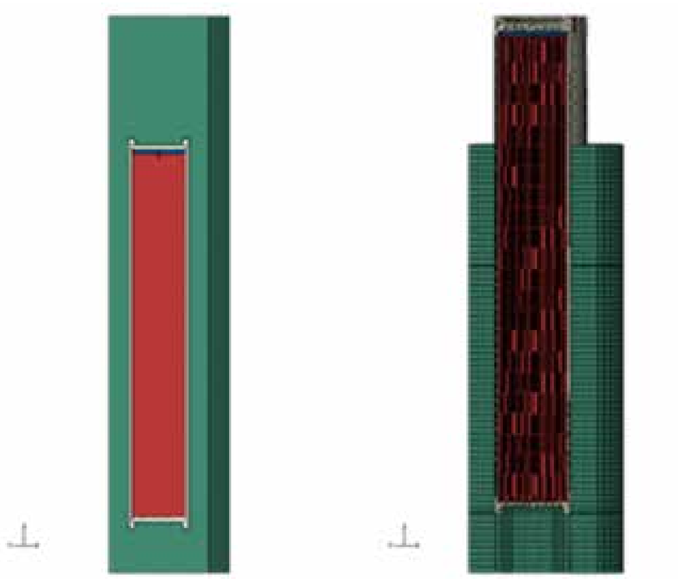


Figure 3. *Plot of geometry for rock shear perpendicular to axis of canister (left) with the ¼ shearing part removed (right).*

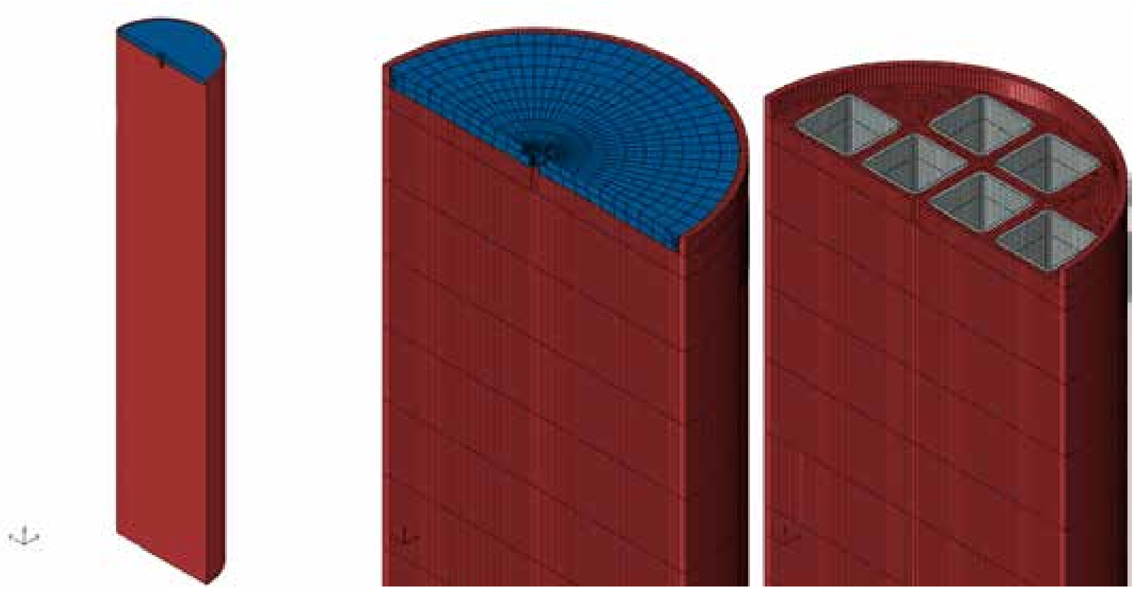


Figure 4. *Insert BWR geometry (left), mesh with lid (mid) and without lid (right).*

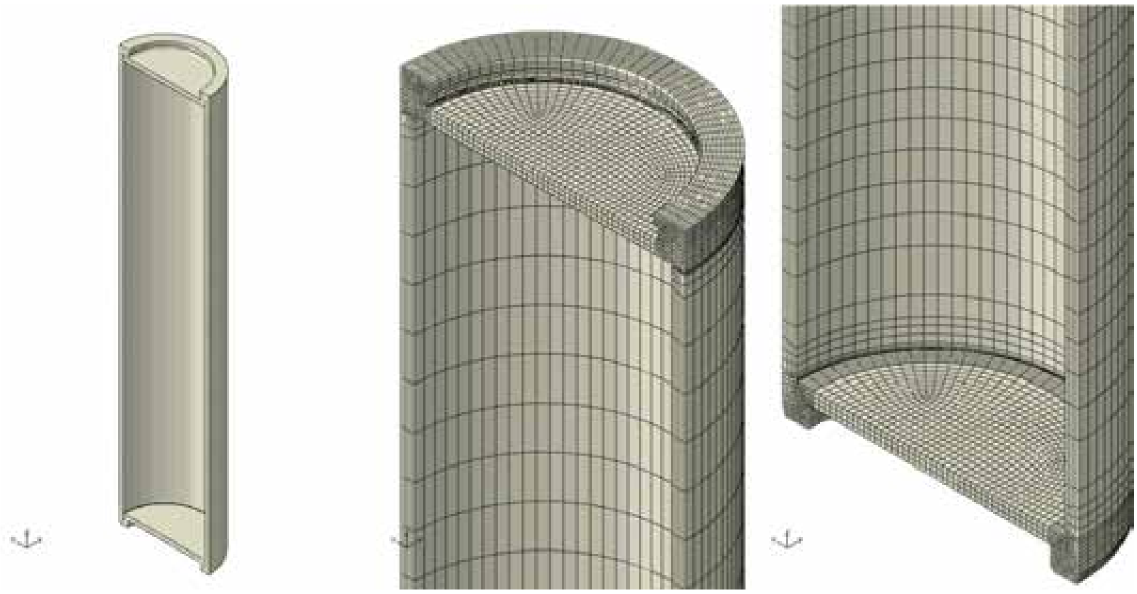


Figure 5. Copper shell geometry (left), mesh top (mid) and mesh bottom (right).

3. Calculations

The calculation technique of the reference case was done with a static procedure and used damping (Stabilize) in order to reach convergent solutions, which is identical to the technique used for SR-Site and described in Hernelind (2010). The calculations with the brittle bentonite were made with a dynamic procedure (quasi-static) and don't need artificial damping.

A large number of calculations have been performed but with severe convergence problems. All attempts with a material model of the bentonite with a fast drop in strength, which directly after reaching maximum deviator (Mises stress) stress goes to zero after a few per cent strain, failed to converge. The most brittle like behaviour that succeeded were the two shown in Figure 2. One (Density 2050 brittle) had a very long plastization before the strength was rapidly reduced while the other one (Density 2050 brittle2) had a rather slow decrease in strength that started early at about 5% strain. In order to simulate that the shear strength has been completely lost a fourth calculation was done with brittle bentonite and with the shear plane of the buffer removed in the shear zone of the bentonite. Table 1 shows the different models.

Table 1. Calculations presented in this report.

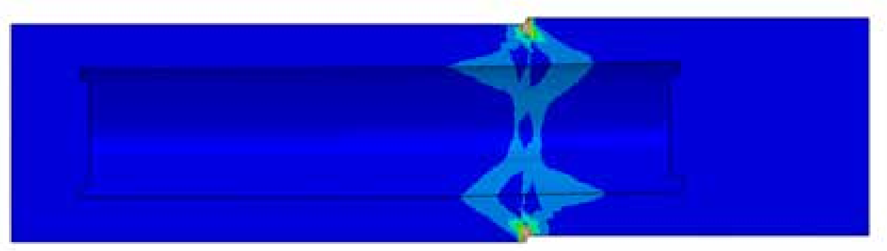
Calculation		Model	Remarks
1	model6g_normal_quarter_2050ca3	bentonite_2050ca3	Reference case
2	model6g_normal_quarter_2050ca3 _brittle_quasi	bentonite_2050ca3_**brittle**	brittle
3	model6g_normal_quarter_2050ca3 _brittle_quasi2e	bentonite_2050ca3_**brittle2**_o ld5	brittle2
4	model6g_normal_quarter_2050ca3 _brittle_quasi2_removed2	bentonite_2050ca3_**brittle2**_o ld5	D:o+Buffer shear plane removed

The calculations have been run to a total shear displacement of 5 cm and the results compared. Calculation 3 was though only possible to run to 4.5 cm displacement, but it is so close to 5 cm that the results can be used for comparison.

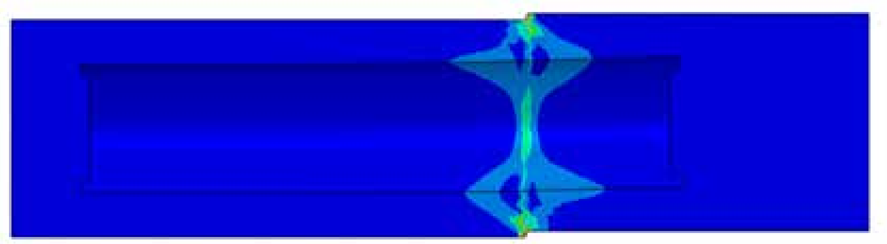
4. Results

The results of the four calculations are shown as the stresses in the buffer, copper shell and cast iron insert.

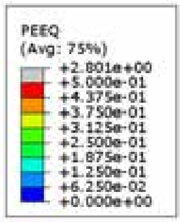
Figures 6 and 7 show the plastic strain in the buffer. Figure 6 shows the entire buffer while Figure 7 shows a part of the shear plane.

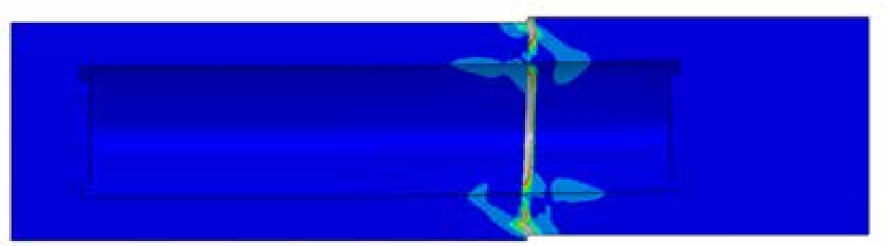


Calc. 1. Reference case. 5 cm shear. Max peeq 2.80

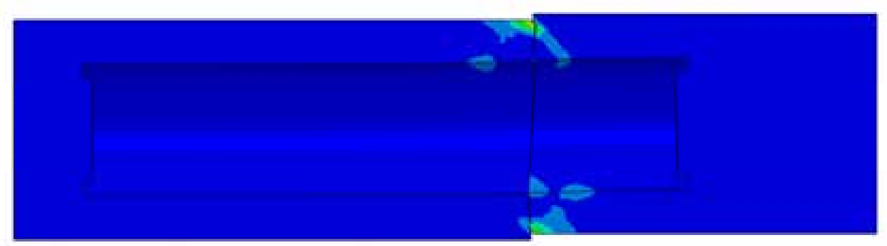


Calc. 2. Brittle. 5 cm shear. Max peeq 3.42





Calc. 3. Brittle2. 4.5 cm shear. Max peeq 2.80



Calc. 4. Brittle2. Shear plane removed. 5 cm shear. Max peeq 5.25

Figure 6. *Plastic strain (peeq) in the buffer.*

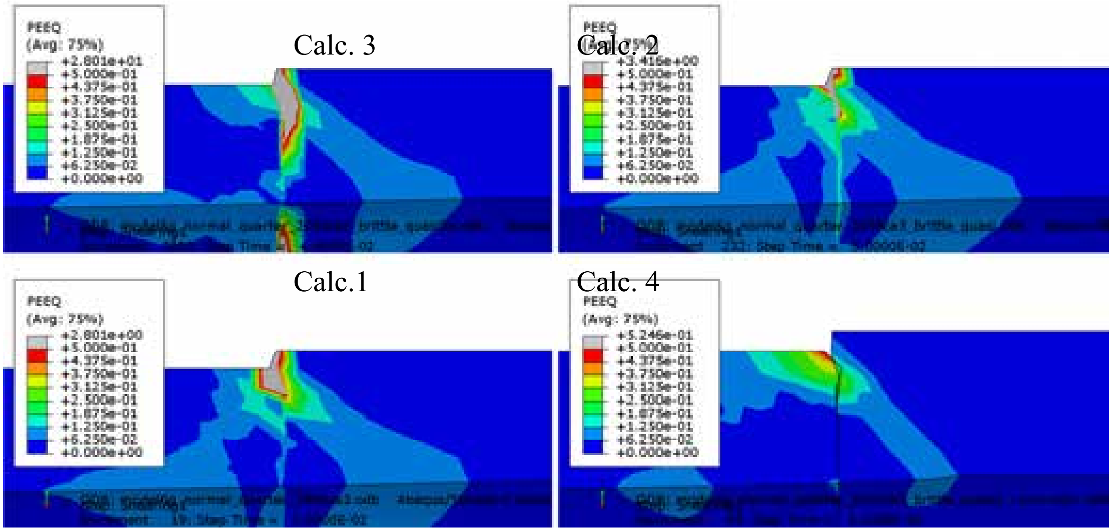
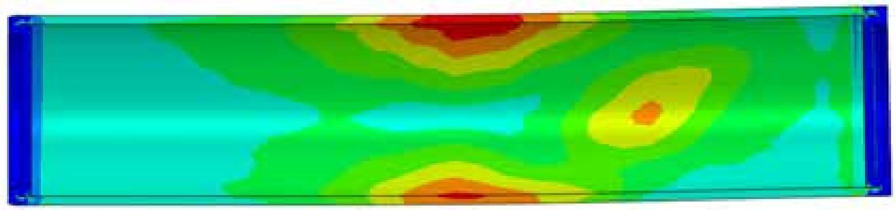


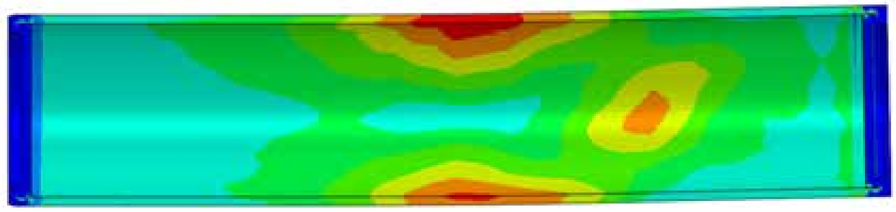
Figure 7. *Plastic strain (peeq) in the buffer close to the shear plane.*

The figures show that the plastic strain in the buffer in the brittle cases differs quite a lot from that in the reference case, except for calculation 2, which has a rather late decrease in shear strength that does not start until after almost 50%. The difference is especially pronounced in calculation 4 where the shear plane is removed, which is natural since the strains will be concentrated to that plane and the stresses released in the surrounding of the shear plane.

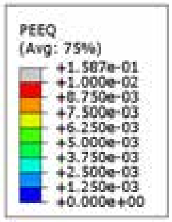
Figure 8 shows the plastic strain in the copper. The most obvious difference occurs in calculation 4 with the buffer shear plane removed, where the stress (or plastic strain) concentration close to the shear plane is larger than in the other cases. Otherwise the difference between the different cases is small.

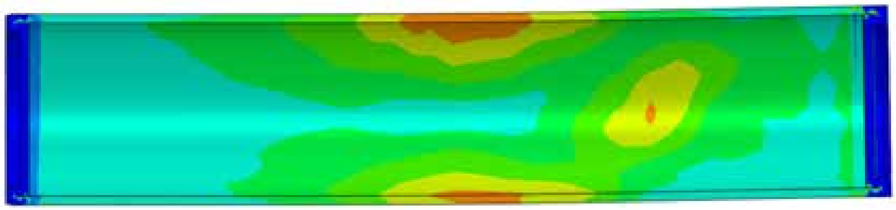


Calc. 1. Reference case. 5 cm shear. Max peeq 0.16

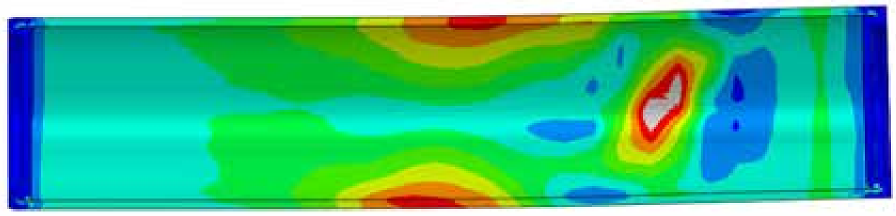


Calc. 2. Brittle. 5 cm shear. Max peeq 0.16





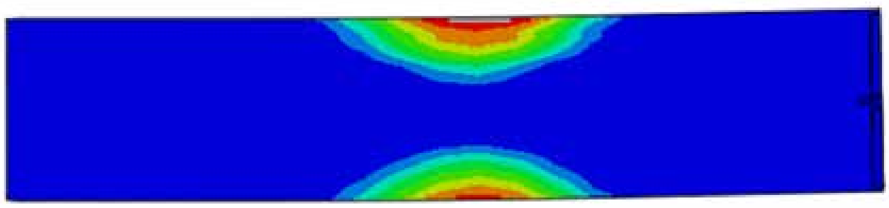
Calc. 3. Brittle2. 4.5 cm shear. Max peeq 0.16



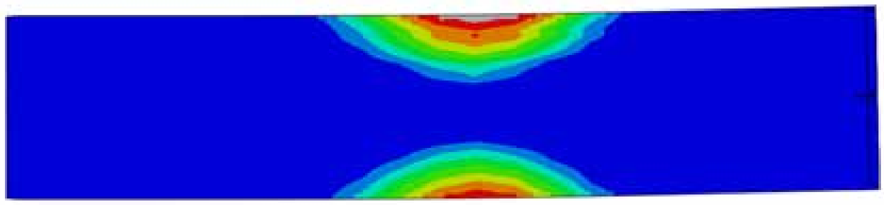
Calc. 4. Brittle2. Shear plane removed. 5 cm shear. Max peeq 0.15

Figure 8. *Plastic strain (peeq) in the copper.*

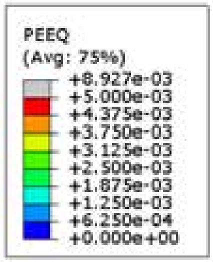
Figures 9 and 10 show the plastic strain in the iron insert. The difference between the calculations is not strong but especially the calculation with the buffer shear plane removed shows slightly higher plastic strain in the centre of the insert although the maximum plastic strain in the insert is lower than in the reference case.

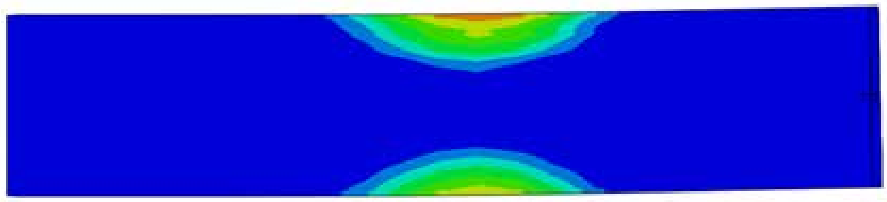


Calc. 1. Reference case. 5 cm shear. Max peeq 0.0089

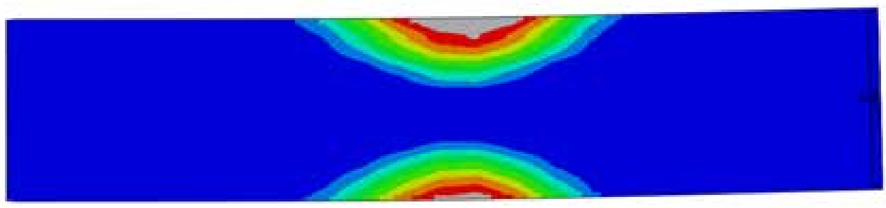


Calc. 2. Brittle. 5 cm shear. Max peeq 0.0107





Calc. 3. Brittle2. 4.5 cm shear. Max peeq 0.0073



Calc. 4. Brittle2. Shear plane removed. 5 cm shear. Max peeq 0.0066

Figure 9. *Plastic strain (peeq) in the insert.*

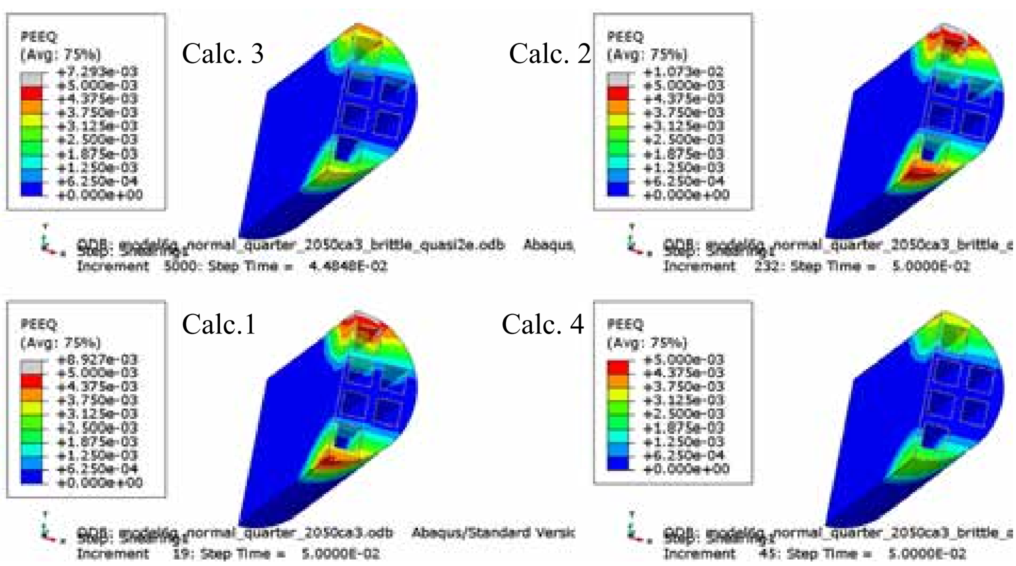


Figure 10. *Plastic strain (peeq) in the iron insert. The insert is cut at a horizontal central section.*

5. Conclusions

Three rock shear calculations with a buffer that shows brittle behaviour have been performed and compared to the reference case with the same buffer properties as used for SR-Site. The influence on the plastic strain in the copper shell was small but the extreme case with the buffer shear plane removed showed clearly higher plastic strain at a point located adjacent to the shear plane. The influence on the plastic strain in the iron insert was also very small and the total plastic strain was not for any case higher than about 1%.

The overall conclusion is thus that brittle failure behaviour of the buffer will not have a strong effect on the consequences of a rock shear. This is a logical conclusion since brittle failure does not mean increased shear strength but decreased shear strength with strain, i.e. the shear resistance of the buffer will decrease and all previous calculations show that higher shear resistance of the buffer means larger stresses in the canister.

References

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SKBdoc 1203875 ver 1.0. Ritningsförteckning för kapselkomponenter. Svensk Kärnbränslehantering AB.

Appendix – Storage of files

This report is based on the results from a lot of FE-simulations using ABAQUS which is a commercial available code and is thus not stored as part of the work. Below is a short description of files used in the project and directories for storage of these. These files are also stored at SKB.

The files are stored in directory Model_report as:

Geometry
Input-files
Plots
PM shear with brittle bentonite.doc - this report
Scripts

Geometry definitions

Contents in C:\Users\jhd\mappar\clay\ssm_questions\brittle buffer\Model_report\Geometry

model6g.cae - ABAQUS/CAE-database
model6g.jnl - ABAQUS/CAE-journal file

Input files used for the simulations

Each analysis is started by abaqus job=input-file (w/o .inp).

Files with extension "incl" are referenced by some of the input-files (extension "inp").

Contents in C:\Users\jhd\mappar\clay\ssm_questions\brittle buffer\Model_report\Input-files

model6g_normal_quarter_2050ca3.inp
model6g_normal_quarter_2050ca3_brittle_quasi.inp
model6g_normal_quarter_2050ca3_brittle_quasi2e.inp
model6g_normal_quarter_2050ca3_brittle2_quasi2_removed2.inp
model6g_material.incl
model6_material_brittle.incl

Plot-files used in the report

Contents in C:\Users\jhd\mappar\clay\ssm_questions\brittle buffer\Model_report\Plots

Scripts used for post-processing

Used inside ABAQUS/CAE or by abaqus cae startup=script.py after appropriate editing of job-name inside the script-file.

Contents in C:\Users\jhd\mappar\clay\ssm_questions\brittle buffer\Model_report\Scripts

compare.py
brittle_post.py