Document ID	Version	Status	Reg no	Page
1515435	1.0	Approved		1 (11)
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Answers to SSM questions 2015-10-12

Abstract

SSM has asked questions regarding creep results for (SKBdoc 1419643 ver 1.0) and (SKBdoc 1399768 ver 2.0) which are answered below.

Sammanfattning

SSM har ställt frågor angående krypresultat presenterade i (SKBdoc 1419643 ver 1.0) och (SKBdoc 1399768 ver 2.0) vilka besvaras nedan.

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Contents

1 Introduction

Creep simulations in copper have been performed for the copper shell of the KBS-3 canister in the final repository of spent nuclear fuel. The FE-code ABAQUS (ABAQUS 2014) has been used for the simulations and when including creep in the simulation a user defined subroutine has been used.

The subroutine is based on the theory for P-doped copper presented by (Andersson-Östling and Sandström 2007).

2 Questions to SKB regarding report (SKBdoc 1419643) rev 1.0

1. In section 1, it can be read that the copper shell material model is based on a creep model developed by Rolf Sandström.

   According to section 4.3, the material model for the short duration analysis (neglecting creep) is based on a simplified elastic-plastic model using data from the creep model assuming a strain rate of $5\cdot10^{-3}$ 1/s. This model is consistent with contour plots showing equivalent plastic strain PEEQ in the report. The model is also consistent with the "*static"-procedure that is used in the analyses according to section 2 in the report.

   According to Appendix 3, each analysis is started by *abaqus job=input-file (w/o .inp) user=creep_rs_march2009*. This means that the user subroutine CREEP is used for the copper material in the analyses. However, no contour plot shows equivalent creep strain CEEQ in the report.

   Which model has been used for the copper material in the analyses? If a simplified elastic-plastic model is used for the copper material, does this mean that no creep strain will develop in the two analyses?

2. Load cases analysed in the report are more or less load controlled. How is it justified that creep in the copper canister is not taken into account in the analyses? (Assuming creep is not considered in the analyses)

3. According to section 7, short term analysis is based on static response but the results will depend on the time used for the simulation since rate-dependent material data is used. According to section 4.1, the strain rate dependence is not needed in this study since the swelling pressure process is very slow. How should the analysis approach be understood?

4. Is the swelling pressure/shear stress applied as a ramp on the copper canister in the analyses? If yes, how does the ramp look like?

5. Is the temperature evolution, in one or another way, considered in the analyses?

6. According to section 1 and with reference to the SKB report TR-10-31, the highest swelling pressure occurs for bentonite with density 2050 kg/m^3 with a magnitude of 12.3 MPa. How has the swelling pressure 12.3 MPa been derived based on TR-10-31? Why is not the swelling pressure 15 MPa given in TR-09-22 (design premises) used?

7. According to section 1 and with reference to the SKB report TR-10-31, the shear stress in the bentonite limited to 1.75 MPa in the report. How has the shear stress 1.75 MPa been derived based on TR-10-31?

8. Is the copper cylinder in contact with the insert when the shear stress and the swelling pressure are applied on the copper cylinder in the second load case? If not, 1) what is the initial gap between the copper cylinder and the insert and 2) is the gap closed during the analysis?

9. According to section 9, strain rate effects in the copper and iron will affect the results. According to section 4.1, the strain rate dependence is not needed in this study since the swelling pressure process is very slow. How should this contradiction be understood?

10. Are there any contour plots of the copper lid region and the copper bottom region showing plastic strains at a component level?

3 Answers to SSM-questions regarding (SKBdoc 1419643)

Question 1:
All analyses in this report are based on an elasto-plastic material model for the copper shell and thus no creep is considered. The analysis could be started with abaqus job=xx user=creep_rs_march2009 but if the material definition not is referencing the subroutine it really doesn't matter. However, I agree on that the documentation of how the analysis should be started is a bit confusing. Obviously the instruction saying abaqus job=xx makes it more clear.

Question 2:
Creep analysis was not specified as part of the assumptions for these analyses. However, regions with large plastic strains (but rather low) are very local and furthermore the stresses are mainly compressive.

Question 3:
The formulations are correct – rate dependent material properties means that the time used for the simulation affects the results. However, for these analyzes this effect is small.

Question 4:
A ramp is a linear variation – in this case the load is zero at step time 0 and 12.3 MPa at step time 1.

Question 5:
No temperatures have been defined for these analyses since this was not part of the assumptions specified for these analyses.

Question 6:
Eqn 3-1 in Börgesson et al. (2010), TR-10-31, gives the swelling pressure 12.5 MPa for density 2050 kg/m^3 – however, the swelling pressure has always been defined to 12.3 MPa for all analysis – probably due to some round-off errors in the calculations. We don't believe this difference is critical. The water pressure 5 MPa has not been added in these calculations since this wasn't specified in the assumptions for the calculations, but I agree on that the water pressure should have been added. However, the magnitude of the plastic strains, PEEQ, shows that this load case is far from being critical and thus the need of adding the water pressure too.

Question 7:
The reference for limiting shear stress is taken from TR-10-31, eqn 3-5 which gives about 3.58 MPa as limiting shear stress for low strain rate (e.g. 1×10^{-8} 1/s). From Dueck et al. (2014) (page 40) one finding is "The friction angle δ seemed to have a value approximately equal to half of the bentonite friction angle $\phi/2$".With limiting shear stress of 3.58 MPa and half of the bentonite friction angle implies a limiting shear stress of about 1.75 MPa for contact between buffer and copper shell.

Question 8:
The initial gap between the copper shell and the insert is 1.56 mm. For the first load case contact is not established, but for load case 2 contact is established partly, see Figure 3-1 in the present report below.

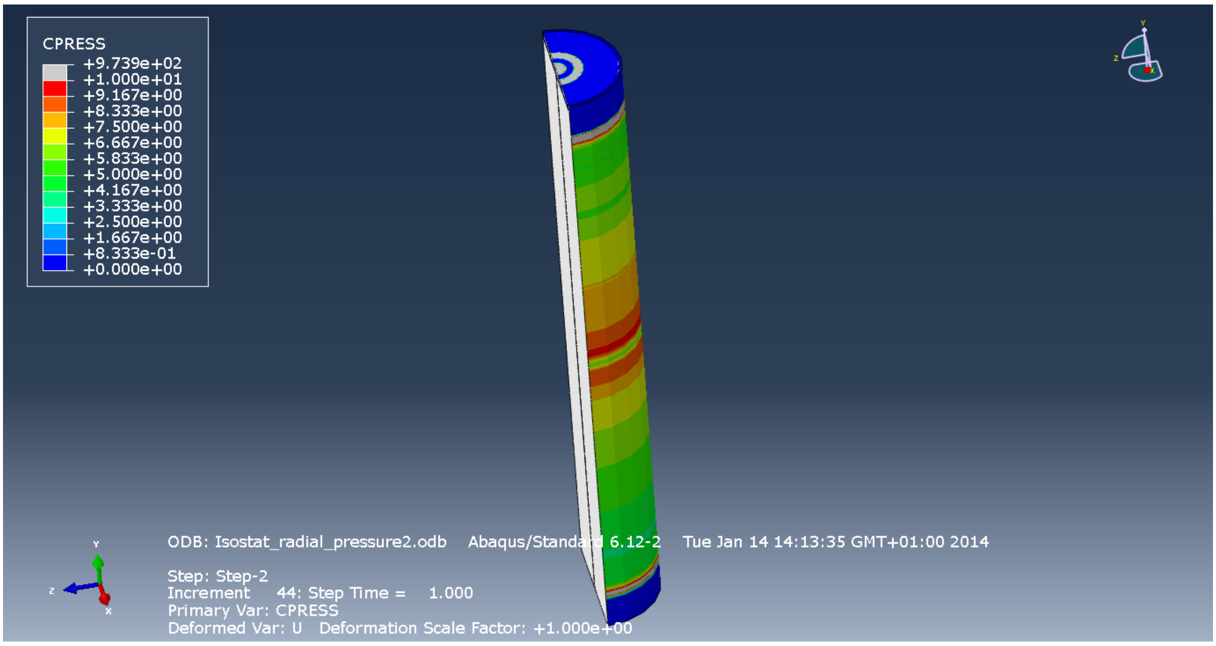

Figure 3-1. *Established contact for load case 2 in (SKBdoc 1419643).*

Question 9:
Rate dependent material definitions affect the results. However, this effect declines with increasing time for the simulation. The material derived for the copper shell is based on a creep definition and calculated for a specific strain rate *($5x10^{-3}/s$)*. Thus the comment in chapter 9 should be interpreted as that a low strain rate is applied when creating the material model.

Question 10:
There are several plots showing PEEQ in the copper shell, e.g. Figure 8-3, 4 and 5. Also Figures A1-4, 6 and A2-4, 6 show PEEQ for the copper shell.

4 Questions to SKB regarding report (SKBdoc 1399768) rev 2.0

1. In figure 2-2, the swelling pressure between 10 and 20000 years is 15 MPa. Is the additional hydraulic pressure of 5 MPa only considered in the design case?

2. Figure 2-5 shows internal pressure as a function of time. For how many years is the canister analysed with an internal pressure of 0.5 MPa?

3. In the four different analyses, is the internal pressure load in figure 2-5 combined with the external pressure load shown in figure 2-2 or 2-3?

4. In figure 4-2 and 4-3, the insert is placed up-side-down with respect to the copper canister. Is the model shown in the figures used in the analyses?

5. Figure 10-2 and figure 10-3 are difficult to compare as they show results from different analyses, i.e. isostat_JLH_creep_red_dim and isostat_JLH_creep_blue_dim. Is it a mistake that results from the latter analysis is shown in figure 10-3? Is a contour plot of minimum principal stress available from the analysis isostat_JLH_creep_red_dim?

6. In figure 10-12 and 10-31, does the x-axis show time from 10^4 to 10^5 years?

7. What explains the sudden increase in creep strain for the isostat_JLH_creep_red_dim analysis in figure 10-12? At what time does it happen?

8. Creep strain development over time is shown in specific elements, see for example figure 10-16. This gives an idea of local effects. Regarding global effects it would be of interest to compare creep strain development just before the onset of the glacial period at time 20000 years with that at time 10^5 years. Are contour plots of CEEQ at time 20000 years available for comparison with results presented in the report? If yes, the same scale as for the contours plots at 10^5 years is preferred.

9. What are the biggest differences between the 2D and the 3D mesh? Major impact on the results caused by these differences?

10. In section 13 it is stated that "*The creep from the internal processes, before external loads are applied, case c) and d), is very small and of minor importance.*" Are there any contour plots available on creep strains caused by this load for case d), i.e. at time 10 years?

11. In section 13 it is written that "*The creep from the internal processes, before external loads are applied, case c) and d), is very small and of minor importance.*" Isn't internal pressure also applied in load case a) and b)?

12. According to figure A1-5 (and the following figures showing results for the time 10 years), gas pressure is applied. Does "gas pressure" correspond to the load described in figure 2-5?

13. Are contour plots with creep strain at a component level available from the *isostat_JLH_creep_red_dim* analysis?

5 Answers to SSM-questions regarding (SKBdoc 1399768)

Questions 1:
Total pressure is swelling pressure (10 MPa) + water pressure at 500 meters depth (5 MPa) = 15 MPa. The dark blue line marked "Pressure 1" in the Figure is thus showing total pressure, not swelling pressure.

Question 2:
Figure 2-5 shows internal gas-pressure versus time. After 10 years this pressure is assumed to be constant (0.5 MPa) for the remaining time.

Question 3:
The internal gas-pressure is included for all analyses as defined by Figure 2-5. Furthermore the external pressure defined by Figures 2-2 and 2-3 is applied.

Question 4:
The plots in Figure 4-3 are wrong. Figure 4-3 should be as below in Figure 4-1 below in the present report.

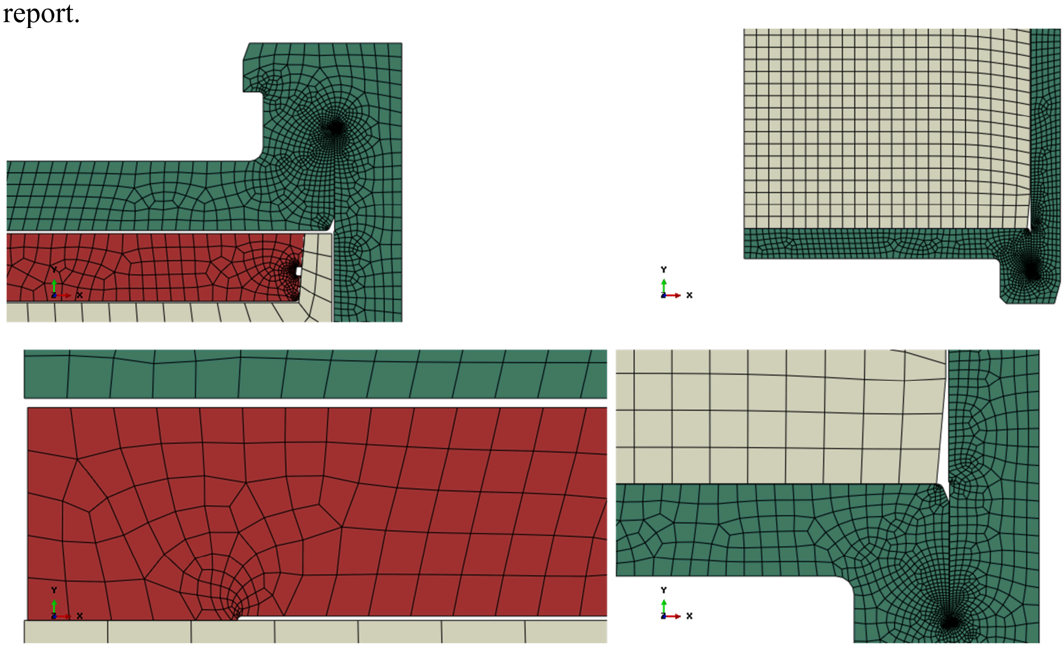

Figure 4-1. *Correct layout of Figure 4-3 in (SKBdoc 1399768).*

Question 5:
The wrong figure was included in Figure 10-3. It should contain results for creep2_red_dim, see Figure 4-2 below in the present report.

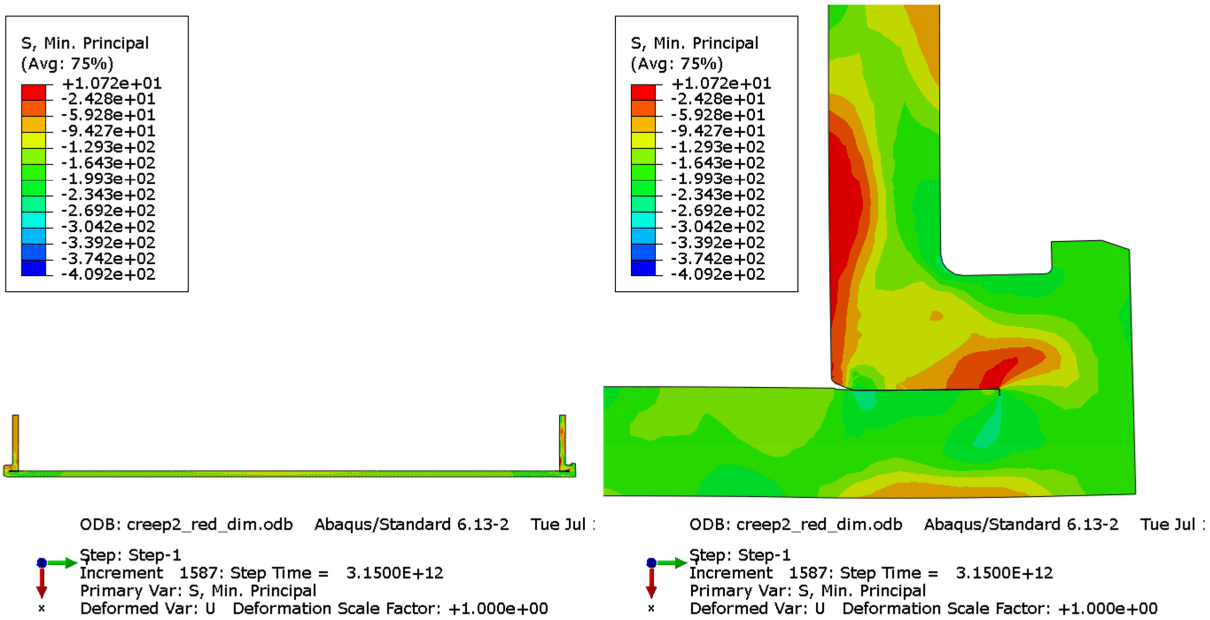

Figure 4-2. Contour plot of minimum principal stress for creep2_red_dim.

Question 6:
Yes, Figure 10-12 and Figure 10-31 both show the results for times between 10 000 and 100 000 years.

Question 7:
The sudden increase in creep strain occurs at 20 000 years when the sudden glaciation load is applied. Note that the creep routine contains all inelastic strain and the high strain rate corresponds to the plastic strain (the creep routine can't distinguish traditional creep strain from traditional plastic strain which means that all inelastic strains will be reported as creep strain).

Question 8:
See Figure 4-3 below in the present report, plot of CEEQ just before 20 000 years (left plot) and at 100 000 years (right plot).

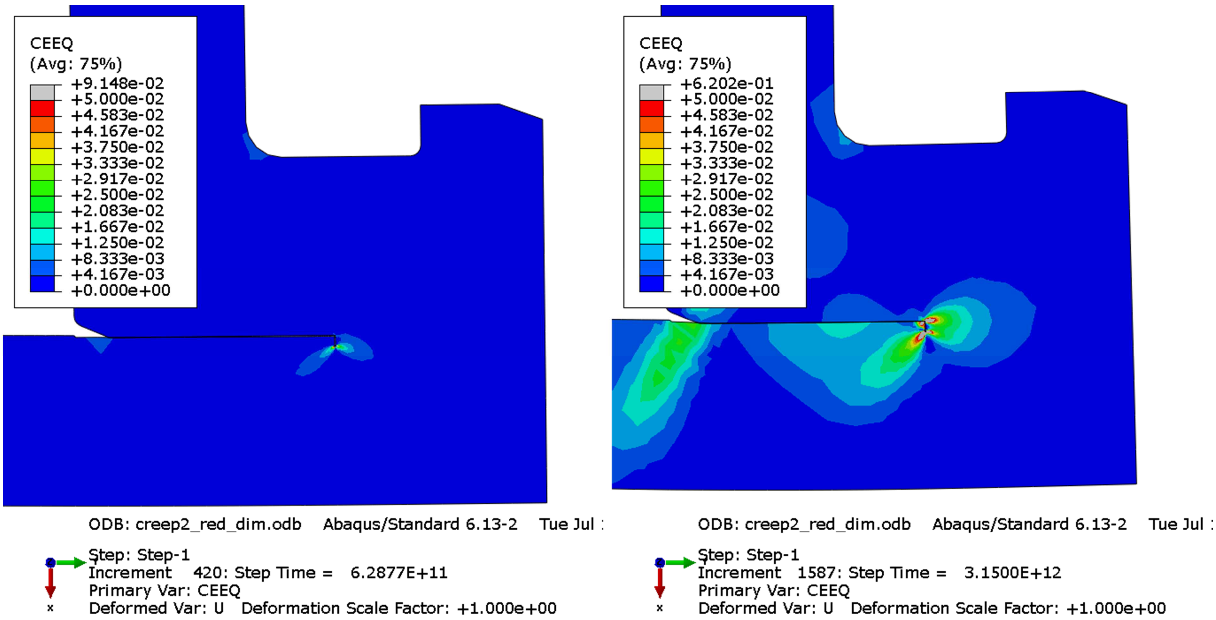

Figure 4-3. *Plot of CEEQ just before 20 000 years (left plot) and at 100 000 years (right plot).*

Question 9:
The axi-symmetric model has a much refined mesh, especially for the copper shell. Also the insert is different, the 3D-model contains the cassette tubes where the axi-symmetric model has a solid insert.

The maximum effective creep strain (CEEQ), Figure 10-39 in SKBDoc 1399768, is as expected lower for the 3D-model compared to the axi-symmetric model but shows similar dependence on the applied load.

Question 10:
Appendices show these plots, e.g Figures A1-3, A1-5, A2-3, A2-5, A3-3, A3-5, A4-3 and A4-5.

Question 11:
Correct – the text should have been cases *a*, *b*, *c* and *d* (see Figures A1-5, A2-5, A3-5 and A4-5)

Question 12:
Yes, the plot corresponds to the case where gas-pressure has been applied.

Question 13:
Appendices 1-4 plots Ax-3, 4, 5 and 6 show contour plots of CEEQ for the copper shell at 10 and 100000 years.

References

SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.se/publications.
References to SKB's unpublished documents are listed separately at the end of the reference list.
Unpublished documents will be submitted upon request to document@skb.se.

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