INSPECTA

TECHNICAL REPORT

SKB

Damage tolerance analysis of PWR-canister inserts for spent nuclear fuel in the case of an earthquake induced rock shear load – Influence of using more detailed models

Report No.: 5000264-2

Revision No.: 1

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Inspecta TECHNICAL REPORT

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Customer SKB	Customer reference Mikael Jonsson

Summary

In this report, a comparison is made between the original model of the PWR insert (using a simplified idealization of the geometry) and a more advanced model where the channel tubes are not tied to the insert and the support plates are modelled separately from the insert. Also, the impact of manufacturing tolerances is evaluated, where the steel tube cassette is shifted so that it is closer to the outside of the insert (i.e. a decreased edge distance where the tensile stresses are high).

The comparison shows that none of the two new models have locally higher stresses compared to the original model.

The original model and the two new models have very similar axial stresses in the most important region for the damage tolerance analysis. This means that it is not necessary to perform a renewed damage tolerance analysis at more positions in the insert or at the location with the smallest distance between the channel tubes and the outside of the insert.

Report title	Index terms
Damage tolerance analysis of PWR-canister inserts for spent nuclear fuel in the case of an earthquake induced rock shear load – Influence of using more detailed models	
Work carried out by Peter Dillström	Distribution ☒ No distribution without permission from the customer or Inspecta Technology AB. ☐ Limited internal distribution in Inspecta Technology AB. ☐ Unrestricted distribution.
Work verified by Lars Alverlind	

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1 INTRODUCTION

SKB has conducted many analyses of the PWR canister insert, which is summarized in the design analysis [1]. When SSM reviewed these analyses [2] they emphasised a need for a number of more detailed analyses of the shear load case. Among other things, SSM wanted that SKB should evaluate the following:

- Impact of the assumption that the steel channel tubes were tied to the insert.
- The manufacturing tolerance of the distance between the channel tubes and insert outer surface and what effect it has on the mechanical integrity.

To answer the above questions, SKB has conducted new analyses for the PWR canister insert [3] which, among other things, evaluate the aspects listed below:

- In the previous analysis [4] it was assumed that the channel tubes were "welded together" with the rest of the insert. The new analysis assumed that the channel tubes are not tied to the insert and therefore the contact problem between channel tubes and the insert is now part of the analysis.
- The channel tubes are welded to support plates in order to create the steel tube cassette. In the previous analysis, the support plates were not modelled, instead they were considered as a part of the insert. In the new analysis, the support plates are modelled separately from the nodular cast iron insert.
- In the previous analysis it was assumed that the steel tube cassette was centered in the insert. In the new analysis the impact of manufacturing tolerances are evaluated, where the steel tube cassette is shifted so that it is closer to the outside of the insert (i.e. a decreased edge distance H as given in Fig. 1-1).

The conclusion from the new analysis [3] is that the results show rather small differences compared to the previous analysis [4] that was based on a much more simplified geometry.

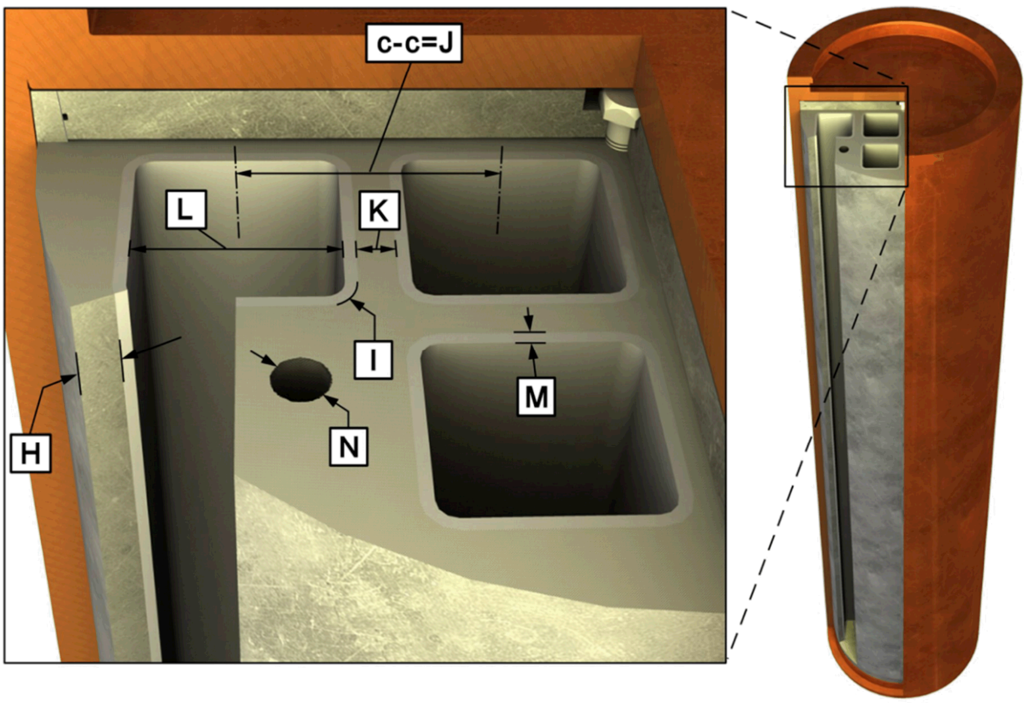

Figure 1-1. The BWR insert with channel tubes, the edge distance H is decreased in the new analysis (the same applies to PWR inserts).

SSM has reviewed the new analyses [5] and would like SKB to clarify the following issues:

- SSM question 2.

  In the new analyses, SKB reports locally higher stresses as compared with the earlier analyses (also in new positions). SSM believes that this means that SKB needs to identify the minimum acceptable defect size at more positions than in the earlier analyses (both in the axial direction and in different parts of a specific cross-section).

- SSM question 3.

  SKB has conducted the analyses so that the minimum distance between the edge of the channel tubes and the insert surface is where the compressive stresses are high. SSM considers it more appropriate to carry out the analysis so as to have high tensile stresses in this area. Moreover SSM wants a new assessment of what this means for damage tolerance of the insert.

SKB has therefore revised the new analyses to ensure that tensile stresses are obtained in the area with the smallest distance between the edge of the channel tubes and the insert surface [7]. Furthermore, in the revised analyses for the BWR insert [6], correct manufacturing tolerances regarding the steel tube cassette shift are introduced (i.e. that an off-set of the steel tube cassette of 10 mm is acceptable [8]). The PWR insert had correct manufacturing tolerances [3, 7].

The purpose of this report is to perform an evaluation of the necessity of a new damage tolerance analysis for the PWR insert. This evaluation will concentrate on the issues raised by SSM [5] (i.e. SSM question 2-3).

2 SUMMARY OF THE ORIGINAL DAMAGE TOLERANCE ANALYSIS

The original damage tolerance analysis is given in [9] using the data from the original global model presented in [4]. In this report we are only interested in the worst case presented in [4, 9] which is going to be compared with the revised global analysis presented in [7]. This means that the following assumptions are used in the evaluation:

- A horizontal shear plane at ¾-distance from the insert base, which is identified as the most severe shear plane position for the insert according to previous studies [7].
- A rock shear = 5 cm shear movement at a velocity of 1 m/s.
- The buffer material has a density of 2050 kg/m^3 (Ca-bentonite).
- A postulated semi-elliptical surface crack (length/depth = 6).

The global model for the original analysis, using a more simplified geometry, is called model6g_PWR_normal_quarter_2050ca3 [4, 9].

2.1 Results from the original damage tolerance analysis

For the design case, bentonite density = 2050 kg/m^3 and shear = 5 cm, the acceptable defect depth = 4.1 mm and the acceptable defect length = 24.6 mm (using the most severe defect geometry assumption of a postulated semi-elliptical surface crack). Other defect geometry assumptions, defect locations and defect orientations give larger acceptable defect sizes.

2.2 Results from the original global model (model6g_PWR_normal_quarter_2050ca3)

For this model the maximum principal stress (326.6 MPa) is equal to the maximum stress in the axial direction of the insert (S33 = 326.5 MPa, see Fig. 2-1). This shows that there are no locally higher stresses in other areas for this model. The position of the maximum tensile stresses is also the position where the postulated semi-elliptical surface crack is analysed (see Fig. 2-2 and 2-3).

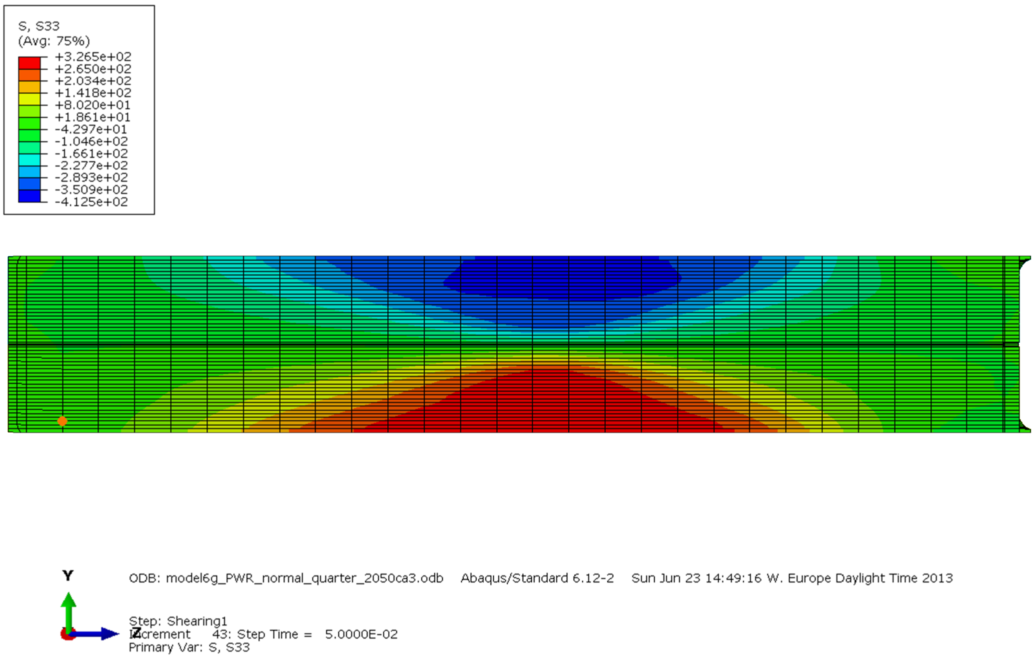

Figure 2-1. The maximum stress in the axial direction (S33) for the model model6g_PWR_normal_quarter_2050ca3 (plot of the entire insert).

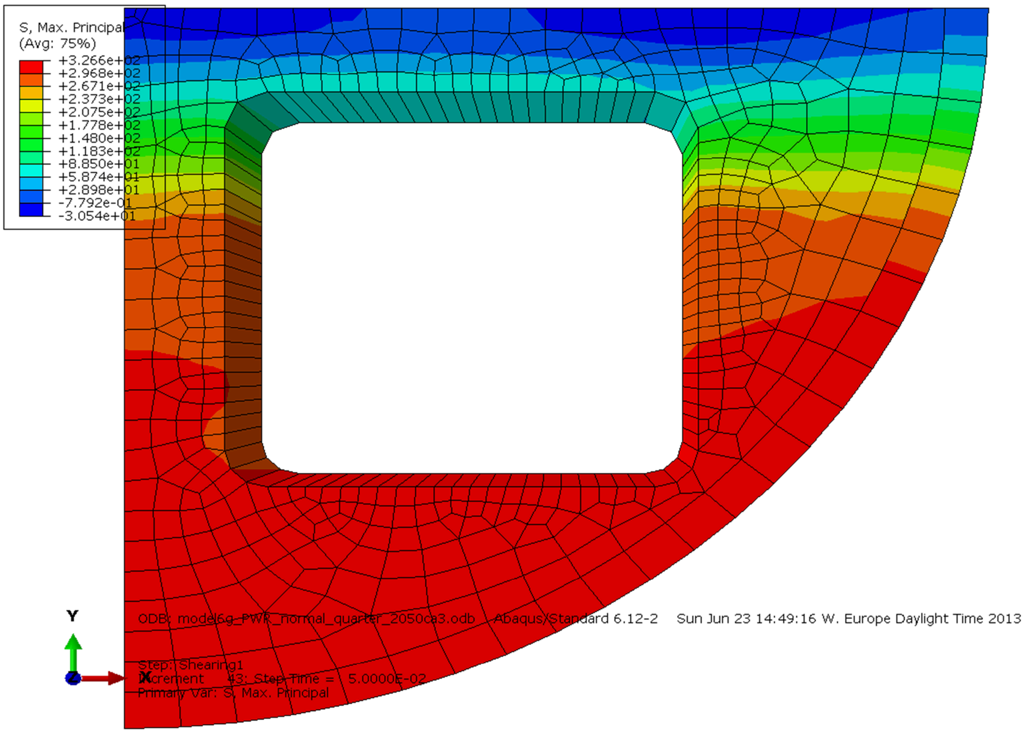

Figure 2-2. The maximum principal stress for the model model6g_PWR_normal_quarter_2050ca3.

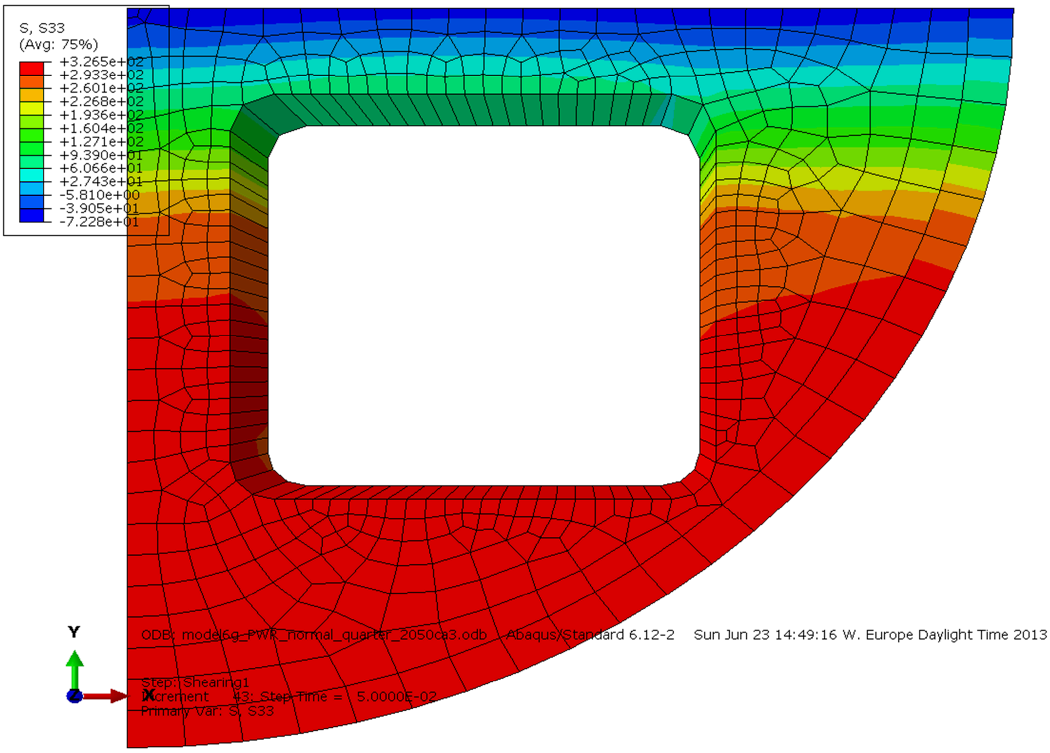

Figure 2-3. The maximum stress in the axial direction (S33) for the model model6g_PWR_normal_quarter_2050ca3.

To be certain that there are no regions with higher tensile stresses, the maximum principal stress at the base and top of the insert is given in Fig. 2-4 and Fig. 2-5.

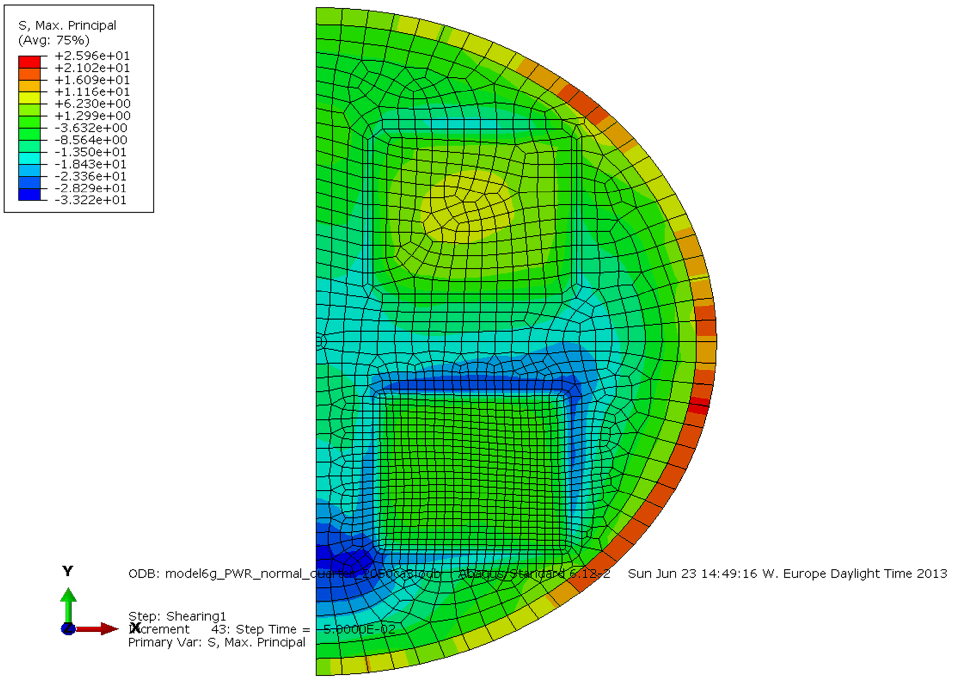

Figure 2-4. The maximum principal stress for the model model6g_PWR_normal_quarter_2050ca3 (at the base of the insert).

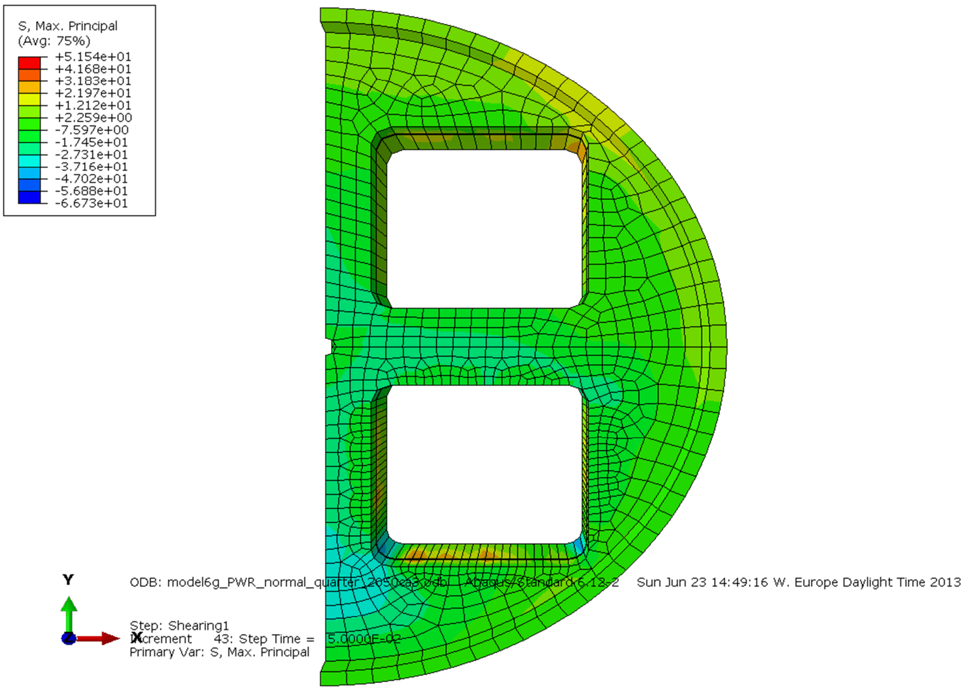

Figure 2-5. The maximum principal stress for the model model6g_PWR_normal_quarter_2050ca3 (at the top of the insert).

As can be seen in Fig. 2-4 and Fig. 2-5, the maximum principal stress at the base of the insert is 26 MPa and at the top of the insert 52 MPa. These stresses are much lower than the stress that is relevant for the damage tolerance analysis (327 MPa) and no additional analysis is needed for this model.

Finally, to simplify the comparison with the new more detailed models, a plot of the axial stress in the most important region for the damage tolerance analysis is given in Fig. 2-6. This axial stress is equivalent to an acceptable defect depth = 4.1 mm [9] (defect length/depth = 6).

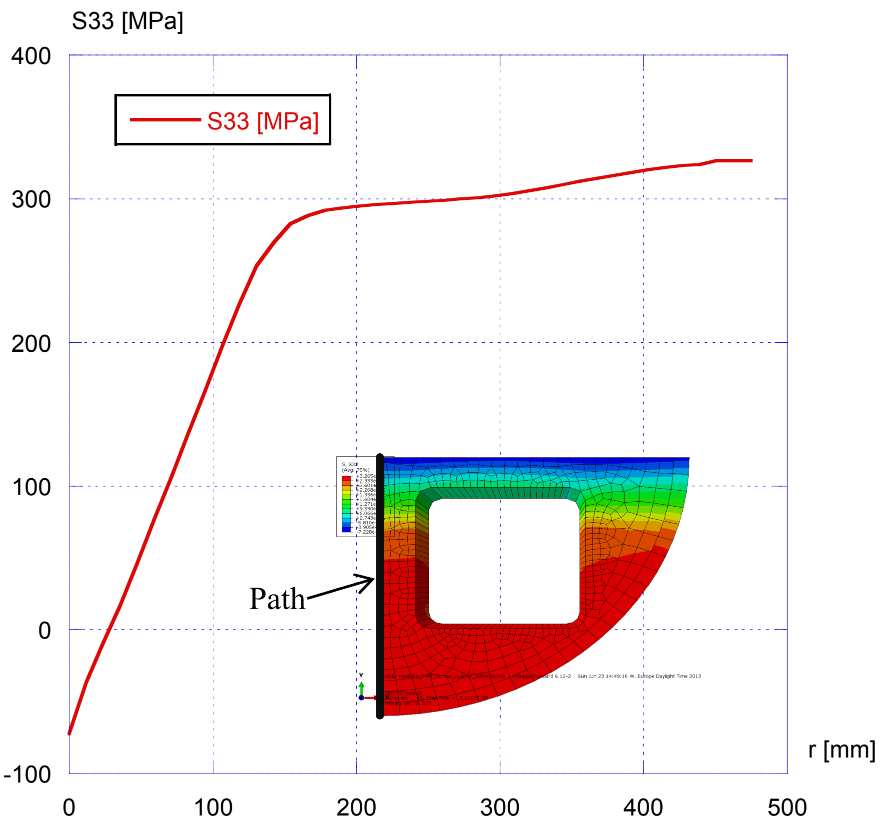

Figure 2-6. A path plot of the stress in the axial direction (S33) for the model model6g_PWR_normal_quarter_2050ca3 (the used path is given as a black line).

This axial stress, given in Fig. 2-6, could be compared with two shear load cases using smaller elastic bending loads where a simplified damage tolerance analysis could be done using ProSACC [10]. An estimate shows that an elastic bending load = 290 MPa is equivalent to an acceptable defect depth = 18 mm and an elastic bending load = 200 MPa is equivalent to an acceptable defect depth = 50 mm. This is summarised in Fig. 2-7.

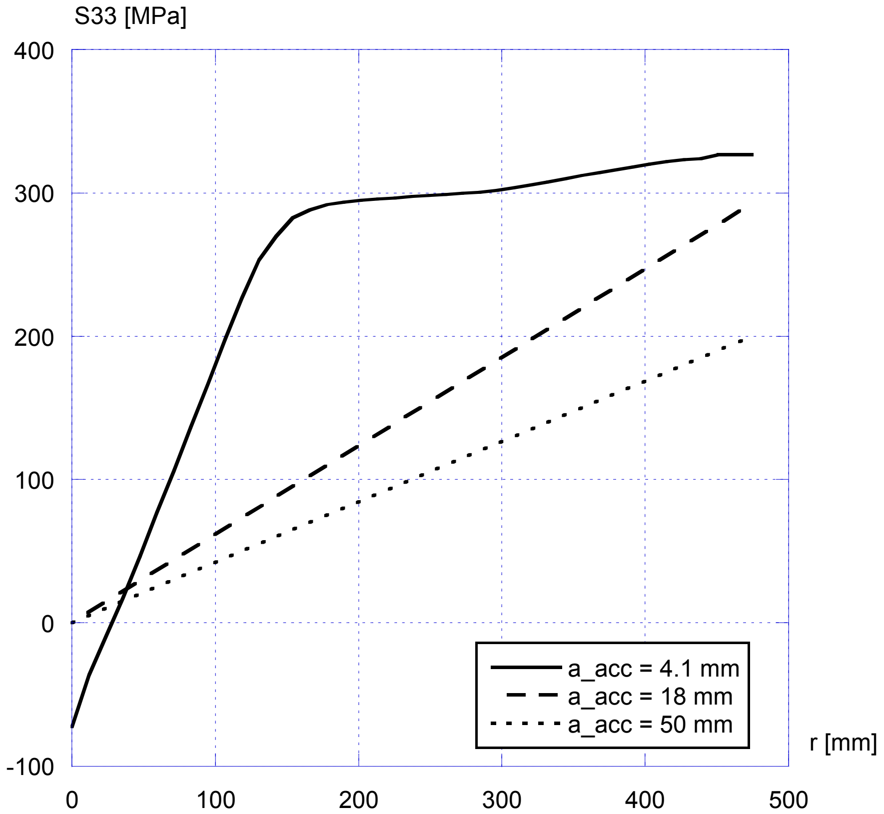

Figure 2-7. Path plots of the stress in the axial direction (S33) using different stress distributions (acceptable defect depths are also given as a function of stresses).

3 RESULTS FROM THE REVISED GLOBAL MODEL (PWR_NEW3_QUASI)

The revised global model pwr_new3_quasi is an idealization of the canister geometry using a half model, where the steel tube cassette was centered in the insert. As given in section 1, the revised global model assumes that the channel tubes are not tied to the insert and therefore the contact problem between channel tubes and the insert is now part of the analysis. Also, the support plates are modelled separately from the insert. More details of the revised model are given in [7].

For this model the maximum principal stress is equal to 333.0 MPa and the maximum stress in the axial direction of the insert, S33, is equal to 332.8 MPa (see Fig. 3-1, 3-2 and 3-3). This shows that there are no locally higher stresses in other areas for this model.

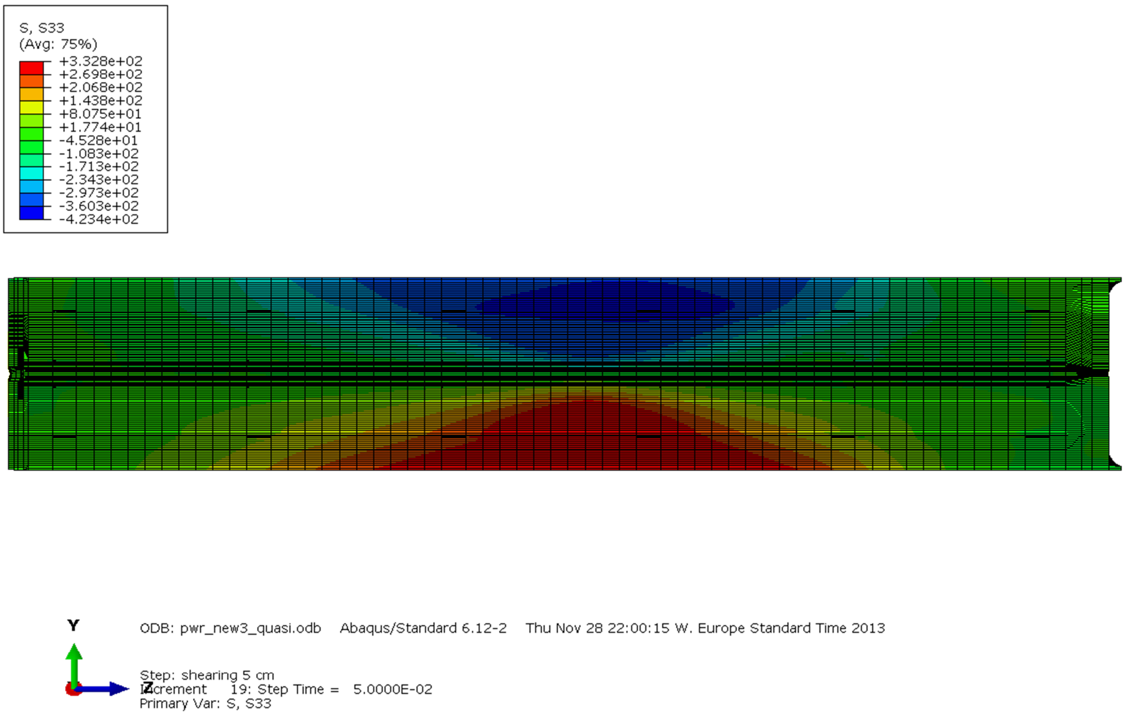

Figure 3-1. The maximum stress in the axial direction (S33) for the model pwr_new3_quasi (plot of the entire insert).

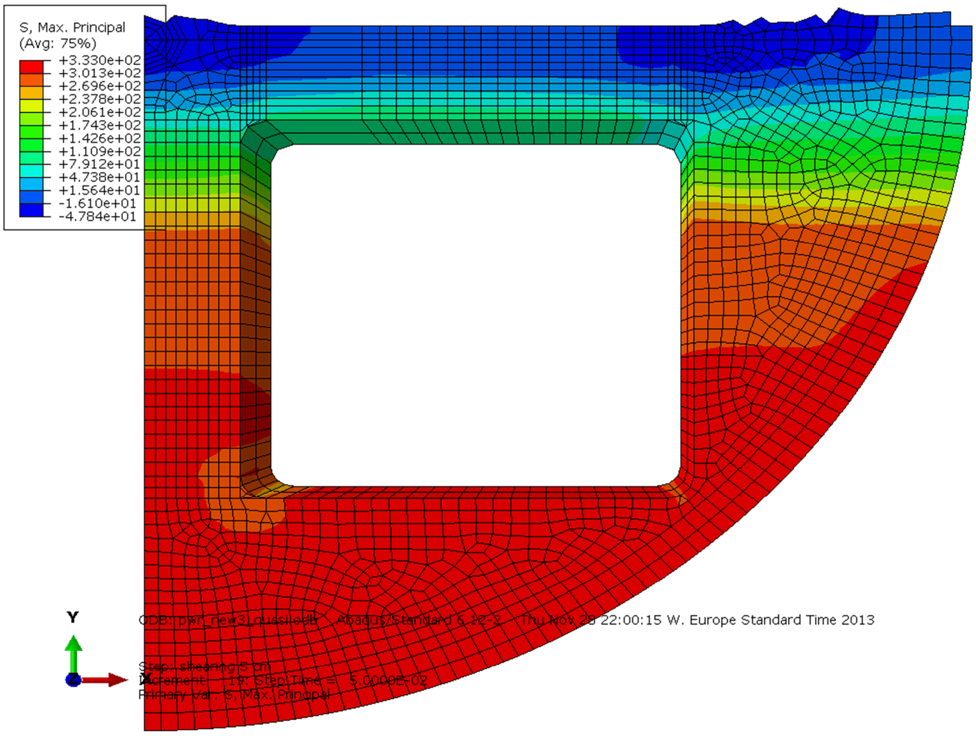

Figure 3-2. The maximum principal stress for the model pwr_new3_quasi.

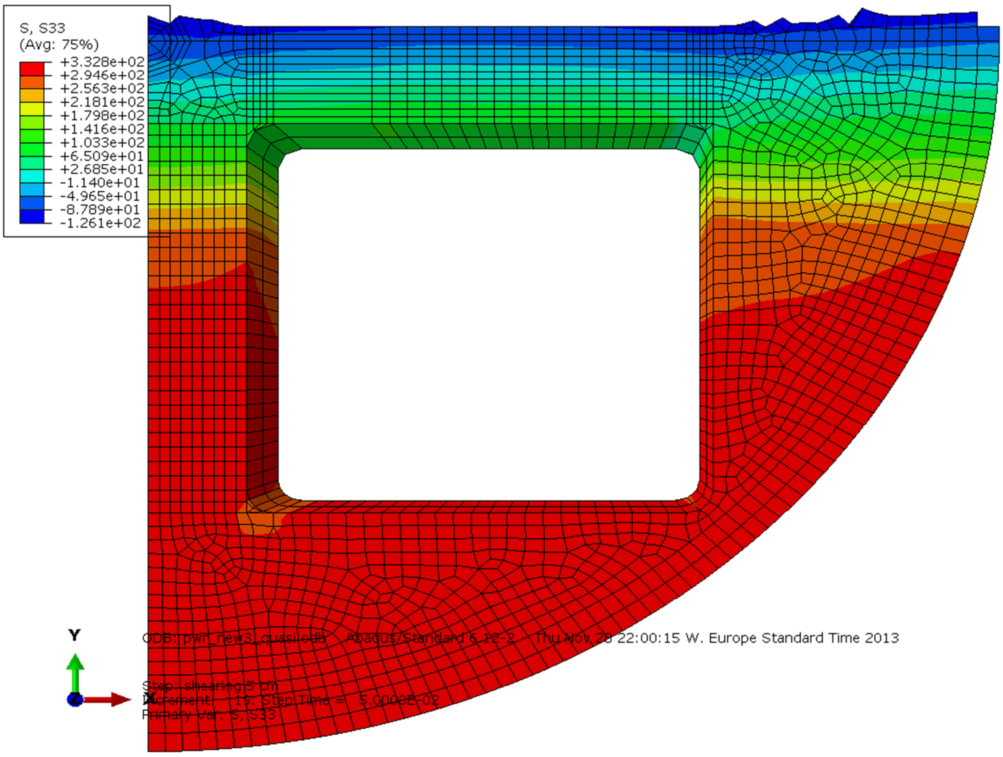

Figure 3-3. The maximum stress in the axial direction (S33) for the model pwr_new3_quasi.

However, the position of the maximum tensile stress is not in the same position as in the original damage analysis. The maximum axial stress (or principal stress), 333 MPa, is located at a position close to the channel tubes as can be seen in Fig. 3-4.

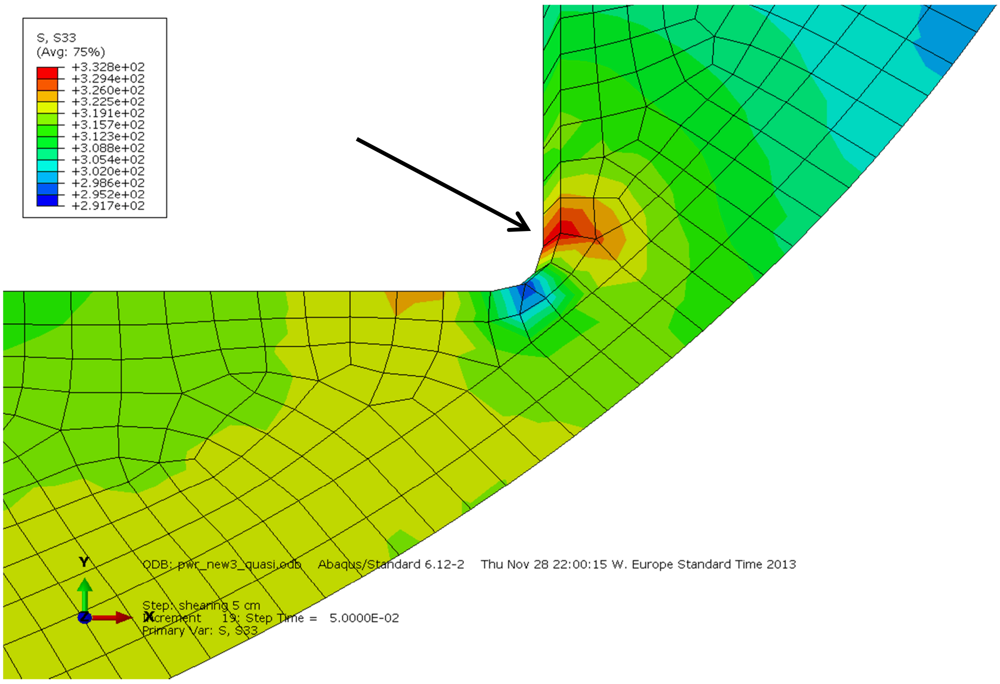

Figure 3-4. Position for the maximum stress in the axial direction (S33) for the model pwr_new3_quasi.

A comparison between the axial stresses close to this stress concentration and the stresses from the original damage analysis shows that the difference is small (see Fig. 3-5). This means that the original damage tolerance analysis should be valid close to the stress concentration.

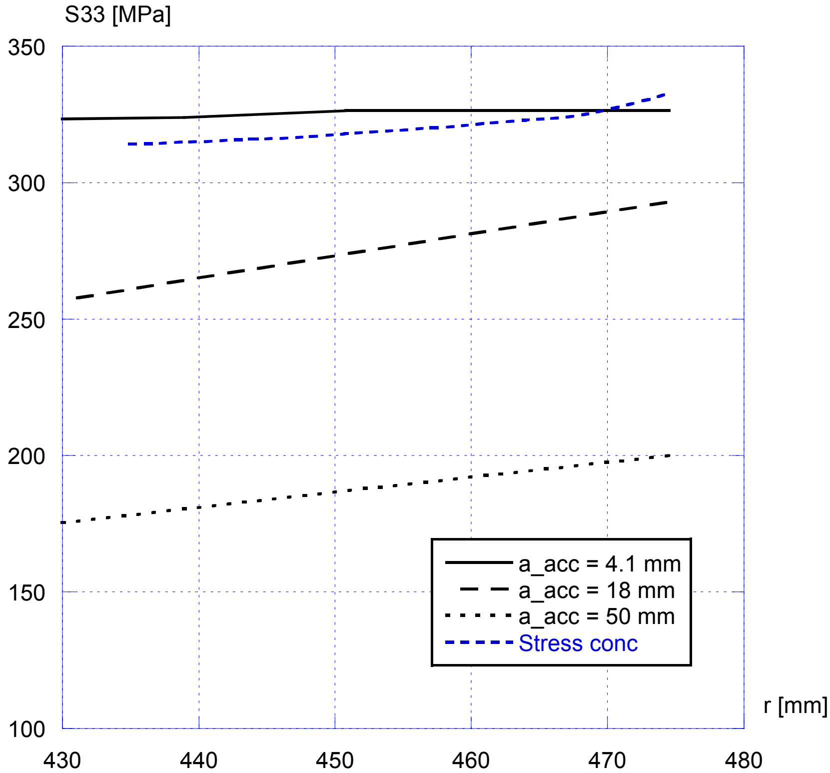

Figure 3-5. Comparison between the axial stresses close to the stress concentration and the stresses from the original damage analysis.

The maximum axial stress (or principal stress) at the same location as in the original damage analysis is given in Fig. 3-6.

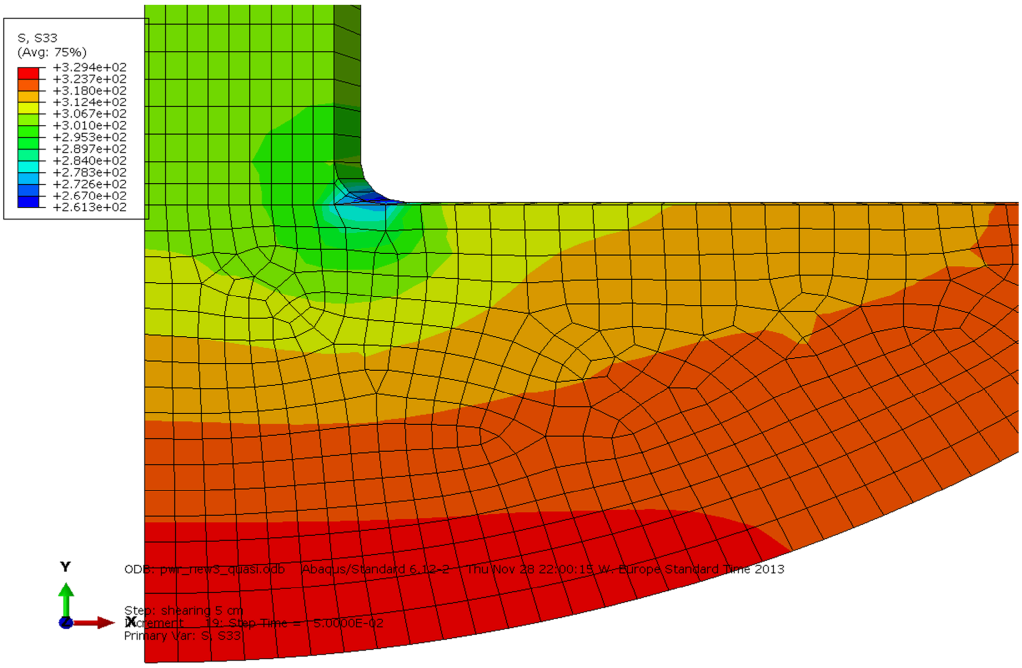

Figure 3-6. The maximum stress in the axial direction (S33) for the model pwr_new3_quasi (at the same location as in the original damage analysis).

As given in Fig. 3-6, the maximum axial stress is 329 MPa. This stress should be compared with the maximum axial stress from the original damage analysis (327 MPa). Since the stresses are almost equal in this section (when comparing the two models), the original damage tolerance analysis should be valid and relevant for this model also.

To be certain that there are no regions with higher tensile stresses, the maximum principal stress at the base of the insert is given in Fig. 3-7 and at the top of the insert is given in Fig. 3-8.

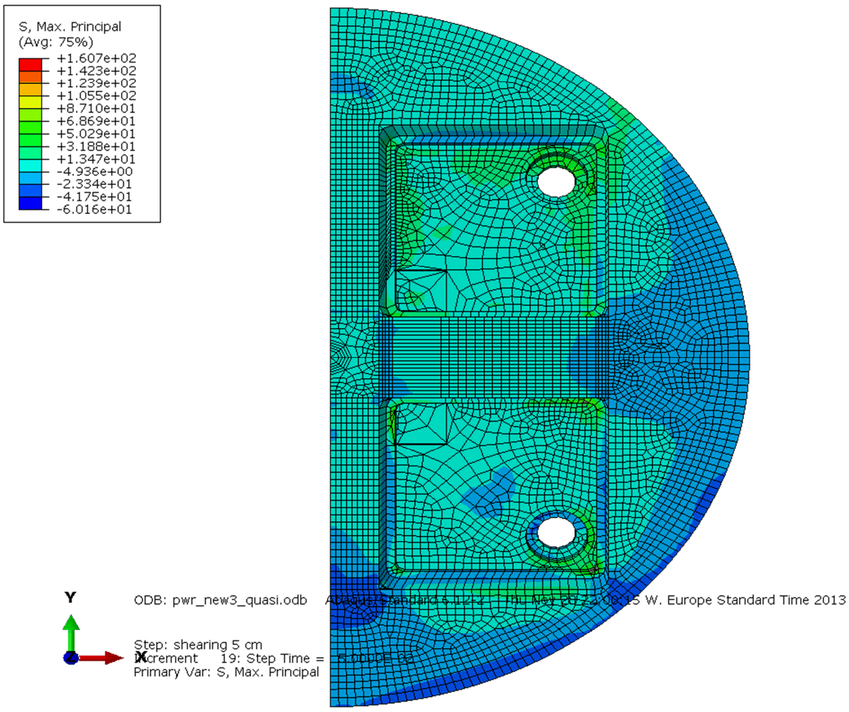

Figure 3-7. The maximum principal stress for the model pwr_new3_quasi (at the base of the insert).

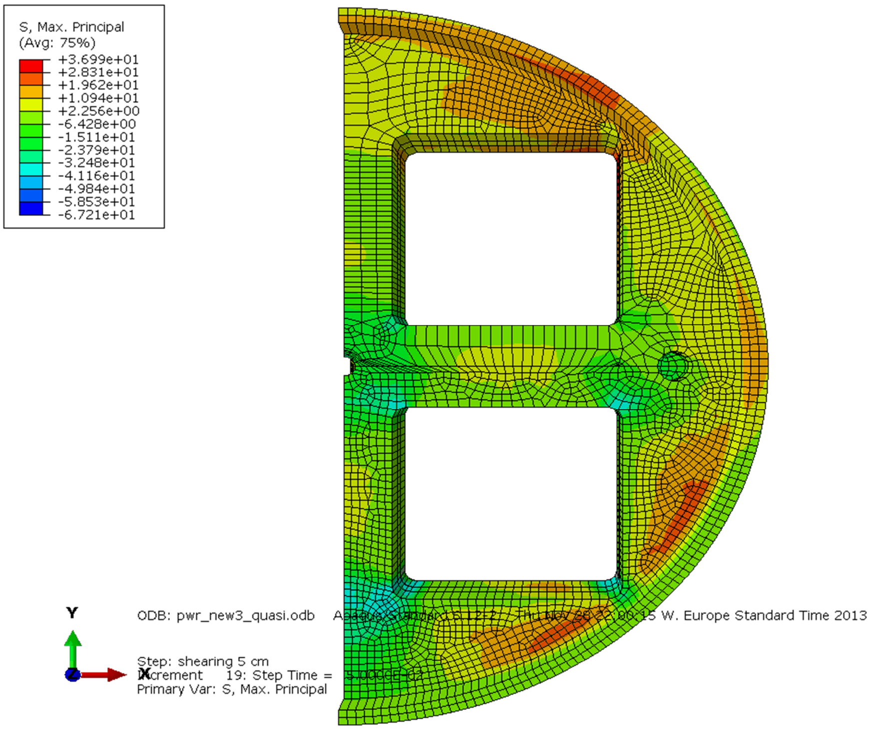

Figure 3-8. The maximum principal stress for the model pwr_new3_quasi (at the top of the insert).

As can be seen in Fig. 3-7 and Fig. 3-8, the maximum principal stress at the base of the insert is 161 MPa and at the top of the insert 37 MPa. The largest stress distribution along a path through the thickness (at the base of the insert), is then compared with the stresses given from the original damage tolerance analysis. This comparison is shown in Fig. 3-9.

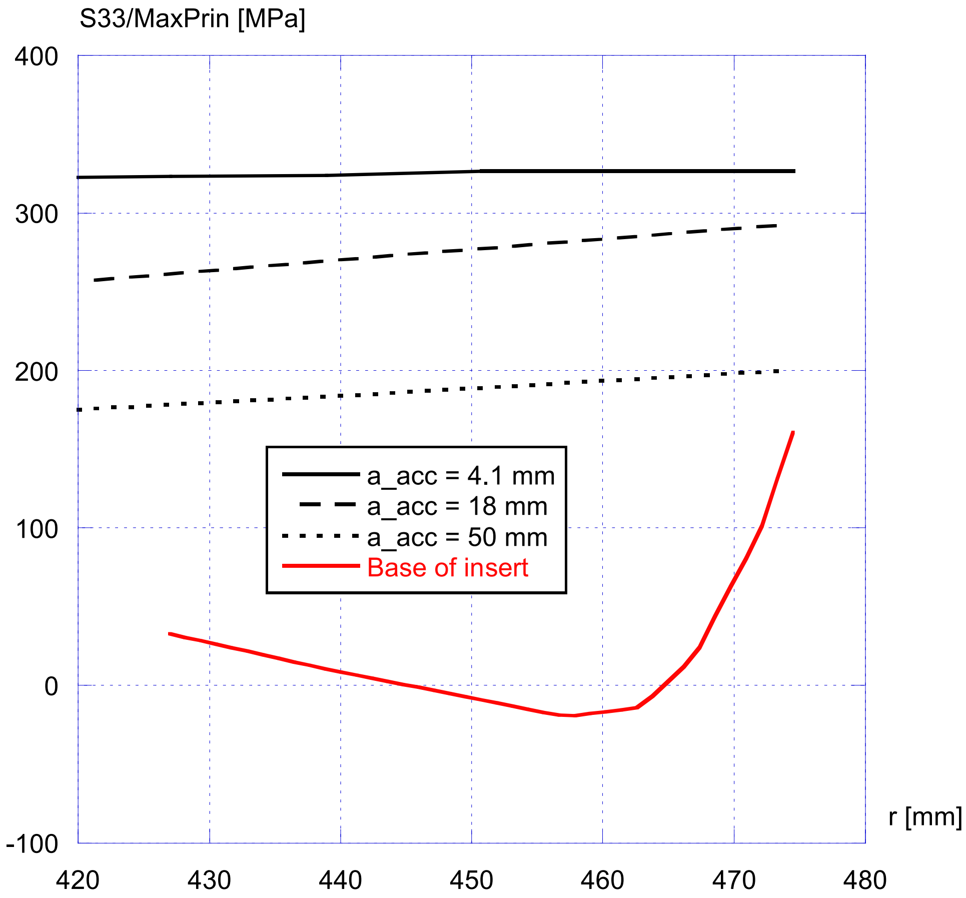

Figure 3-9. Comparison using different stress distributions (acceptable defect depths from the original damage tolerance analysis are also given as a function of stresses).

As given in Fig. 3-9, the stress at the base of the insert is much lower than the stress that is relevant for the damage tolerance analysis (327 MPa) and no additional damage tolerance analysis is needed for this model.

4 RESULTS FROM THE REVISED GLOBAL MODEL (PWR_ECCENTRIC3B_QUASI)

The revised global model pwr_eccentric3b_quasi is an idealization of the canister geometry using a half model, where the steel tube cassette is shifted towards the surface of the insert (i.e. a decreased edge distance as given in Fig. 1-1), but the insert are not rotated. As given in section 1, the revised global model assumes that the channel tubes are not tied to the insert and therefore the contact problem between channel tubes and the insert is now part of the analysis. Also, the support plates are modelled separately from the insert. More details of the revised model are given in [7].

For this model the maximum principal stress is equal to 328.1 MPa and the maximum stress in the axial direction of the insert, S33, is also 328.1 MPa (see Fig. 4-1). This shows that there are no locally higher stresses in other areas for this model. The position of the maximum tensile stresses is also the position where the postulated semi-elliptical surface crack was analysed in the original damage analysis (see Fig. 4-2 and 4-3).

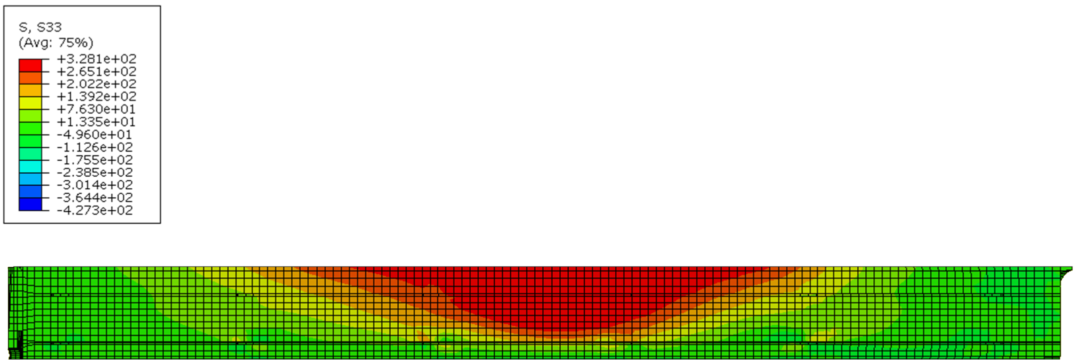

Figure 4-1. The maximum stress in the axial direction (S33) for the model pwr_eccentric3b_quasi (plot of the entire insert).

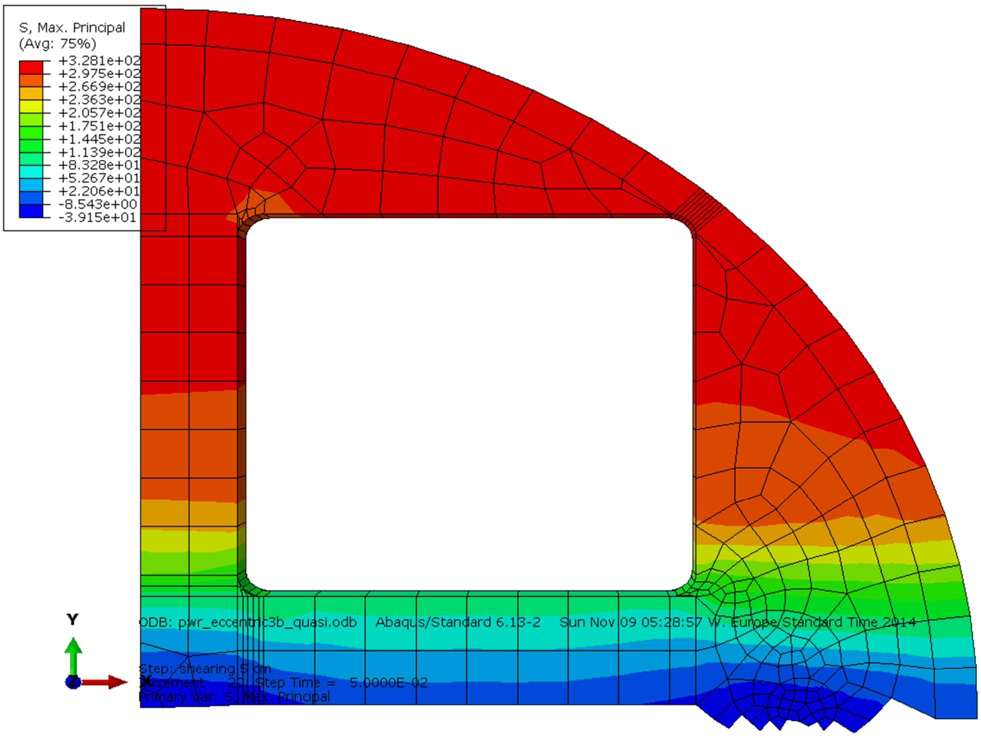

Figure 4-2. The maximum principal stress for the model pwr_eccentric3b_quasi.

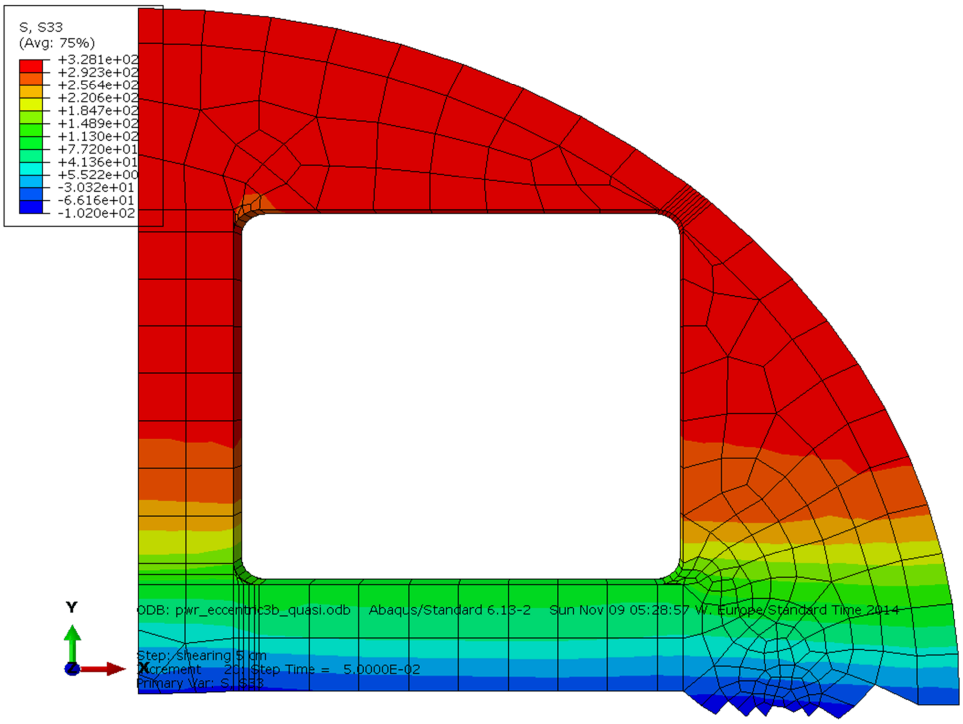

Figure 4-3. The maximum stress in the axial direction (S33) for the model pwr_eccentric3b_quasi.

As given in Fig. 4-3, the maximum axial stress is 328 MPa. This stress should be compared with the maximum axial stress from the original damage analysis (327 MPa). Since the stresses are almost equal in this section (when comparing the two models), the original damage tolerance analysis should be valid and relevant for this model also.

To be certain that there are no regions with higher tensile stresses, the maximum principal stress at the base of the insert is given in Fig. 4-4 and at the top of the insert is given in Fig. 4-5.

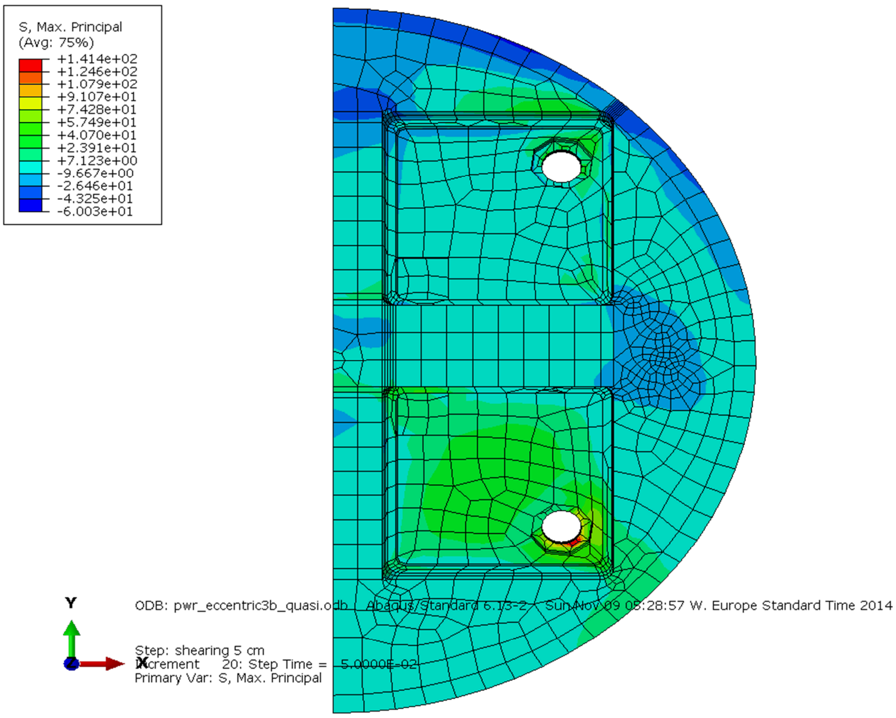

Figure 4-4. The maximum principal stress for the model pwr_eccentric3b_quasi (at the base of the insert).

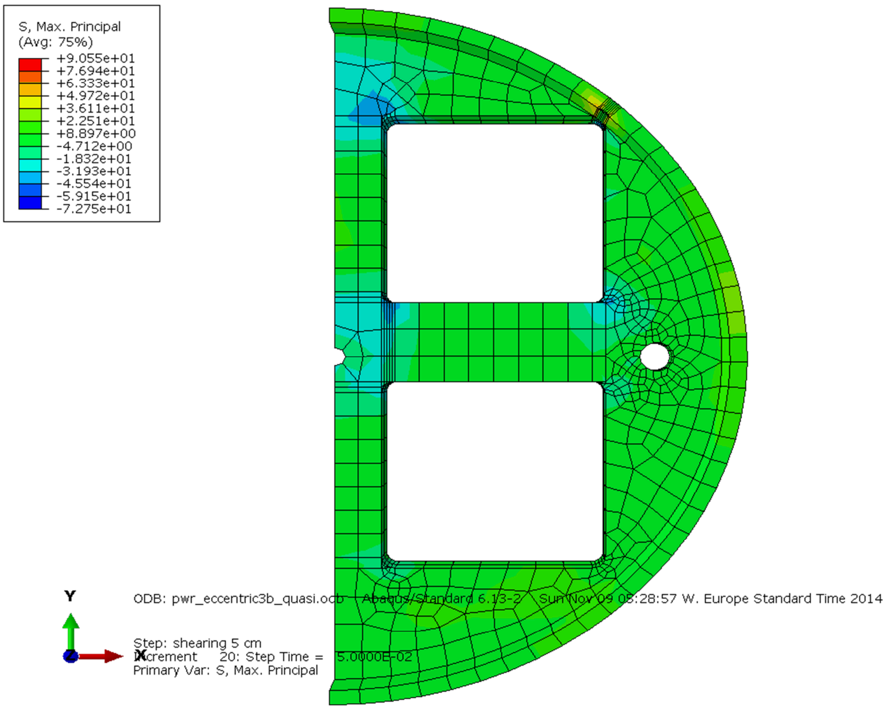

Figure 4-5. The maximum principal stress for the model pwr_eccentric3b_quasi (at the top of the insert).

As can be seen in Fig. 4-4 and Fig. 4-5, the maximum principal stress at the base of the insert is 141 MPa and at the top of the insert 91 MPa. The largest stress distribution along a path through the thickness (at the base of the insert), is then compared with the stresses given from the original damage tolerance analysis. This comparison is shown in Fig. 4-6.

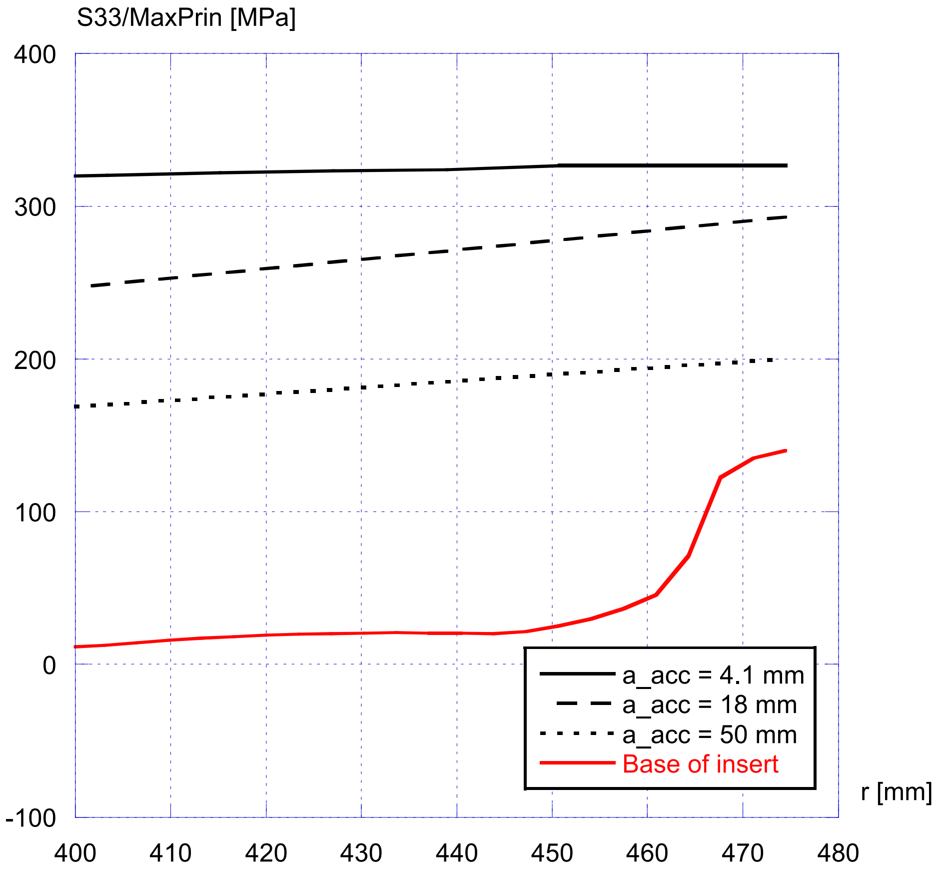

Figure 4-6. Comparison using different stress distributions (acceptable defect depths from the original damage tolerance analysis are also given as a function of stresses).

As given in Fig. 4-6, the stress at the base of the insert is much lower than the stress that is relevant for the damage tolerance analysis (327 MPa) and no additional damage tolerance analysis is needed for this model.

5 SUMMARY AND CONCLUSIONS

In this report, a comparison is made between the original model of the PWR insert (using a simplified idealization of the geometry) and a more advanced model where the channel tubes are not tied to the insert and the support plates are modelled separately from the insert. Also, the impact of manufacturing tolerances is evaluated, where the steel tube cassette is shifted so that it is closer to the outside of the insert (i.e. a decreased edge distance where the tensile stresses are high).

The comparison shows that none of the two new models have locally higher stresses compared to the original model.

The original model and the two new models have very similar axial stresses in the most important region for the damage tolerance analysis. This means that it is not necessary to perform a renewed damage tolerance analysis at more positions in the insert or at the location with the smallest distance between the channel tubes and the outside of the insert.

6 REFERENCES

[1] RAIKO, H., SANDSTRÖM, R., RYDÉN, H. and JOHANSSON, M., (2010-04), "Design analysis report for the canister", SKB Technical Report TR-10-28, Swedish Nuclear Fuel and Waste Management Co.

[2] BRICKSTAD, B., (2012-09-11), "Begäran om komplettering av ansökan om slutförvaring av använt kärnbränsle och kärnavfall - kapselns mekaniska integritet", SSM2011-2426, Strålsäkerhetsmyndigheten.

[3] HERNELIND, J., (2014-02-13), "Detailed models for PWR- and BWR-canisters for Earthquake induced rock shearing", SKB Public Report, DocID 1415152, Ver. 2.0, Swedish Nuclear Fuel and Waste Management Co.

[4] HERNELIND, J., (2010-08), "Modelling and analysis of canister and buffer for earthquake induced rock shear and glacial load", SKB Technical Report TR-10-34, Swedish Nuclear Fuel and Waste Management Co.

[5] —, (2014-03-12), "Protokoll från avstämningsmöte SSM-SKB angående kapselns mekaniska integritet, tillverkningsaspekter samt kontroll och provning", Dok.nr: SSM2011-1137-58, Strålsäkerhetsmyndigheten.

[6] HERNELIND, J., (2014-10-15), "Detailed models for BWR-canisters for Earthquake induced rock shearing", SKB Internal Report, DocID 1439722, Ver. 1.0, Swedish Nuclear Fuel and Waste Management Co.

[7] HERNELIND, J., (2015-01-20), "Detailed models for PWR-canisters for Earthquake induced rock shearing", SKB Public Report, DocID 1439730, Ver. 1.0, Swedish Nuclear Fuel and Waste Management Co.

[8] —, (2013-10), "Design, production and initial state of the canister", SKB Technical Report TR-10-14, Updated 2013-10, Swedish Nuclear Fuel and Waste Management Co.

[9] DILLSTRÖM, P., BOLINDER, T. and E. BONNAUD, (2014-01-31), "Analysis of PWR canister inserts using data acquired from PWR material", Technical Report 50010510-1, Rev. 8, Inspecta Technology AB, SKBdoc 1288288 - Ver. 2.0.

[10] DILLSTRÖM, P., and W. ZANG., (2004), "User manual ProSACC Version 1.0", DNV Research Report 2004/02, Det Norske Veritas AB, Stockholm, Sweden.

7 TABLE OF REVISIONS

Rev	Reason for change/Pages or chapters	Our reference	Date
0	—	Peter Dillström	2014-11-24
1	The report is revised according to the review comments in SKBDoc 1460689, Ver. 0.8.	Peter Dillström	2015-01-29