SKI Report 2003:12

Research

Mechanical Integrity of Copper Canister Lid and Cylinder

Sensitivity Study

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SKI perspective

Background and purpose of the project

The integrity of the canister is an important factor for long-term safety of the repository for spent nuclear fuel. The mechanical integrity of the canister might be affected by different degradation mechanisms. Depending on different conditions i.e. loading intensity, loading mode and temperature etc, different degradation mechanisms can have a possible harmful effect on the mechanical integrity of the copper canister. In a previous projekt reported as SKI report 2003:05, FEM calculations were made to get an understanding of which degradation mechanism are most interesting, with regard to their harmful effect on the canister. The calculations were made using the conditions in the repository and the canister design (presented by SKB) as boundary data.

During that work it became obvious that sensitivity analysis were necessary to clarify the effect of design and creep parameters. This report presents the results of sensitivity analysis.

Results

A sensitivity analysis is performed to clarify the effect of design and creep parameters. Results of this analysis are reported in this report.

Using the results of sensitivity analysis regarding creep, one has to be aware of effect of the creep equation and the creep parameters used. Using other parameters would change the results completely.

Effects on SKI work

The study will be a basis for coming SKI research projects and SKI reviews of SKB's RD&D-programme.

Project information

Responsible for the project at SKI has been Behnaz Aghili.
SKI reference: 14.9-020096/02065.

SKI Report 2003:12

Research

Mechanical Integrity of Copper Canister Lid and Cylinder

Sensitivity Study

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August 2002

Summary

This report is part of a study of the mechanical integrity of canisters used for disposal of nuclear fuel waste. The overall objective is to determine and ensure the static and long-term strength of the copper canister lid and cylinder casing.

The canisters used for disposal nuclear fuel waste of type BWR consists of an inner part (insert) of ductile cast iron and an outer part of copper. The copper canister is to provide a sealed barrier between the contents of the canister and the surroundings.

The study in this report complements the finite element analyses performed in *Reference 1*. The analyses aim to evaluate the sensitivity of the canister to tolerances regarding the gap between the copper cylinder and the cast iron insert. Since great uncertainties regarding the material's long term creep properties prevail, analyses are also performed to evaluate the effect of different creep data on the resulting strain and stress state.

The report analyses the mechanical response of the lid and flange of the copper canister when subjected to loads caused by pressure from swelling bentonite and from groundwater at a depth of 500 meter. The loads acting on the canister are somewhat uncertain and the cases investigated in this report are possible cases. Load cases analysed are:

- Pressure 15 MPa uniformly distributed on lid and 5 MPa uniformly distributed on cylinder.
- Pressure 5 MPa uniformly distributed on lid and 15 MPa uniformly distributed on cylinder.
- Pressure 20 MPa uniformly distributed on lid and cylinder.
- Side pressures 10 MPa and 20 MPa uniformly distributed on part of the cylinder.

Creep analyses are performed for two of the load cases.

For all considered designs high principal stresses appear on the outside of the copper cylinder in the region from the weld down to the level of the lid lower edge. Altering the gap between lid and cylinder and/or between cylinder and insert only marginally affects the resulting stress state. Fitting the lid in the cylinder with zero gap relocates the peak tensile stresses from the weld further down on the cylinder. A smaller gap between the cylinder casing and the insert is to prefer as regards stresses in the region close to the weld and further down on the outside of the cylinder.

From the analyses employing different creep equations it can be concluded that the structure behaviour differs considerably. Thus, in order to assess the long-term effects of the loads acting on the cylinder casing, the material creep behaviour must be more closely described.

Sammanfattning

Den här rapporten är en del av en studie av de mekaniska hållfasthetsegenskaperna hos behållare som ska användas för kärnbränsleavfall. Det övergripande syftet är att bestämma och säkerställa den statiska hållfastheten och långtidshållfastheten hos kopparbehållaren.

Behållarna som ska användas för kärnbränsleavfall av typ BWR består av en insats av gjutjärn och en yttre kapsel tillverkad av koppar. Den slutna kopparkapseln ska skydda omgivningen mot innehållet i behållaren.

Studien i den här rapporten kompletterar de finita elementanalyserna som är utförda i *Referens 1*. Avsikten med analyserna är att utvärdera kopparkapselns känslighet för toleranser vad avser distansen mellan kopparcylindern och gjutjärnsinsatsen. Eftersom stora osäkerheter råder i fråga om materialets krypegenskaper utförs även analyser för att undersöka effekten av olika krypdata på det resulterande spännings- och töjningstillståndet.

Rapporten analyserar den mekaniska responsen hos kopparkapselns lock och fläns när den utsätts för yttre tryck som uppstår p g a svällande bentonit och från grundvattnet på ett djup av 500 meter. Krafterna som verkar på behållaren är något osäkra och de fall som analyseras i den här rapporten är möjliga fall. De lastfall som analyseras är följande:

- tryck 15 MPa på locket och 5 MPa på cylindern,
- tryck 5 MPa på locket och 15 MPa på cylindern,
- tryck 20 MPa på locket och cylindern samt
- sidotryck 10 MPa och 20 MPa på del av cylindern.

Krypanalyser utförs för två av lastfallen.

För samtliga utvärderade utföranden på kapseln uppstår höga dragspänningar på utsidan av kopparcylindern i området från svetsen ner till den nivå som är i höjd med lockets nedre kant. Att ändra distansen mellan lock och cylinder och/eller mellan cylinder och insats har enbart en begränsad effekt på det resulterande spänningstillståndet. Genom att passa in locket i cylindern utan distans flyttas de höga spänningarna från området kring svetsen till ett område längre ner på cylindern. En mindre distans mellan cylindern och insatsen är att föredra vad avser spänningar i området kring svetsen.

Slutsatsen från krypanalyserna där olika krypdata har använts är att beroende p vilken krypekvation som används är det stor skillnad i hur kapseln uppträder. För att kunna utvärdera långtidseffekten av de laster som verkar på cylindern måste därför materialets krypegenskaper kunna beskrivas närmare.

Contents

Appendices

1 Introduction

The canister used for disposal of nuclear fuel waste of type BWR consists of an inner part (insert) of ductile cast iron and an outer part of copper. The copper canister is to provide a sealed barrier between the contents of the canister and the surroundings.

This report is part of a work to ensure the mechanical integrity of canisters used for disposal of nuclear fuel waste. The overall objective is to determine the static and long-term strength of the copper canister lid and cylinder.

The work in this report is a complement to *Report 49-009-001/002* [1] and presents a sensitivity study performed to examine the influence of gap distance between copper cylinder and cast iron insert on the deformation and stress state in the lid-cylinder weld region, and to assess the effect of different creep parameters.

Material data, geometry, load cases, FE model and analysis procedures are described in *Reference 1*. Subsequent sections describe the specifics of the current analyses.

2 Design parameters

The region analysed is shown in *Figure 1*.

The design and geometrical dimensions of the copper canister are based on *Reference 3* and *4*. Two designs are analysed in this report. The designs differ in initial gap distance between the copper cylinder and the insert, see *Figure 2*; cylinder/insert gap distance 1 mm and 2 mm, respectively, is analysed.

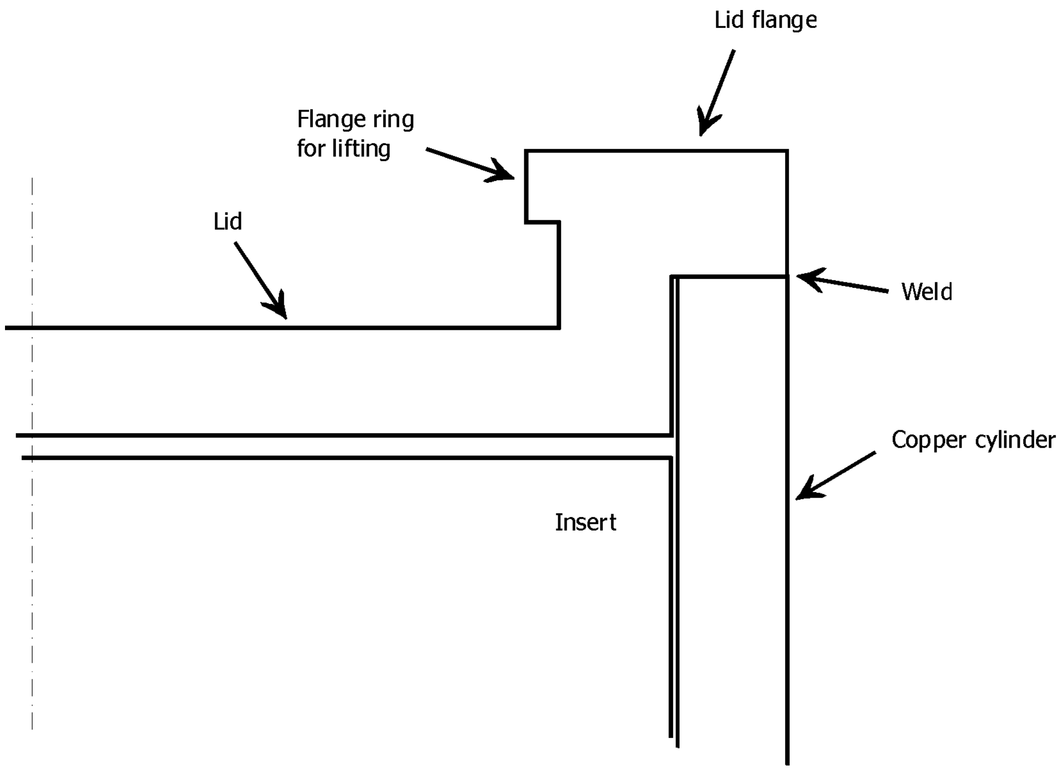


Figure 1 Analysis region of the copper canister lid and cylinder casing.

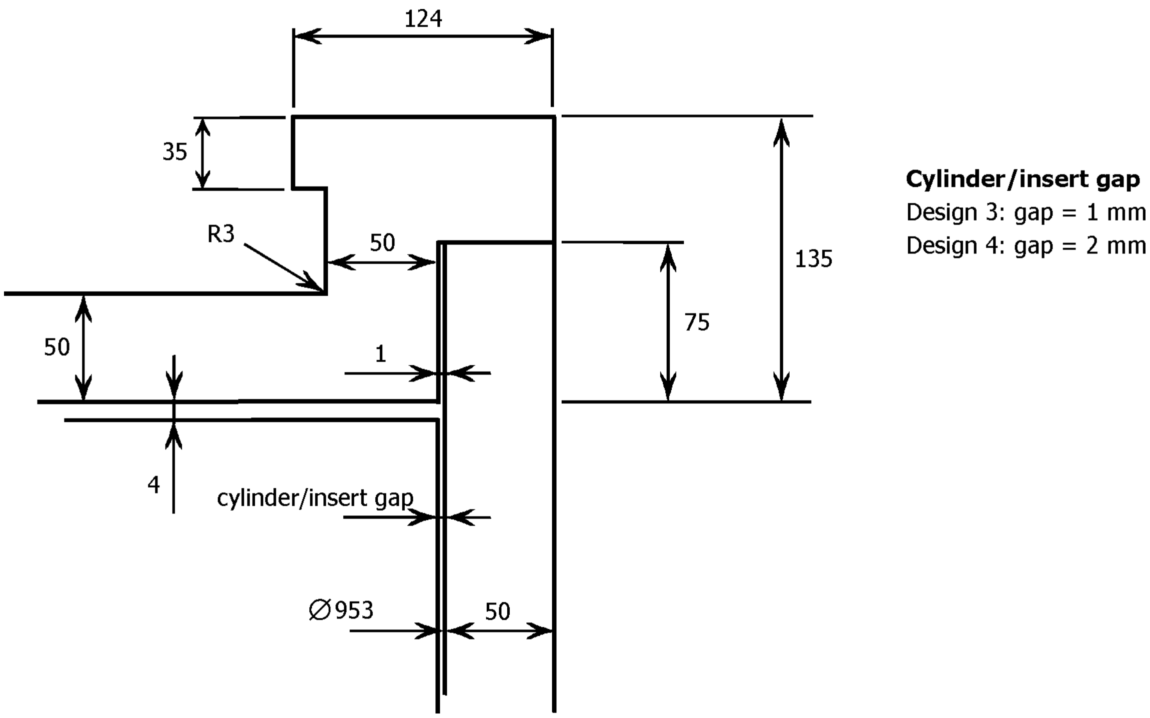


Figure 2 Dimensions used in the current FE analyses [3,4]. For design 1 and 2 see Reference 1.

3 Creep parameters

A discussion of creep behaviour and creep properties is found in *Reference 2*.

Analyses performed in this report assumes a secondary creep rate of 1% for 100 years at a temperature of 100°C and a stress level of 100 MPa, and a linear stress dependency according to [*2*]:

$$\frac{d\varepsilon}{dt} = k \cdot \left(\frac{\sigma}{\sigma_0}\right)^n$$

Two different creep behaviours are analysed and compared. Creep data are based on creep properties reported in *Reference 2* and on data from *Reference 5*. The creep equations are illustrated in *Figure 3* as creep strain rate as a function of stress.

Creep equation 1 [2]:

k=1·10^{-4} 1/year
σ_0=100 MPa
n=1

Creep equation 2 [5]:

k=1·10^{-4} 1/year
σ_0=100 MPa
n=4

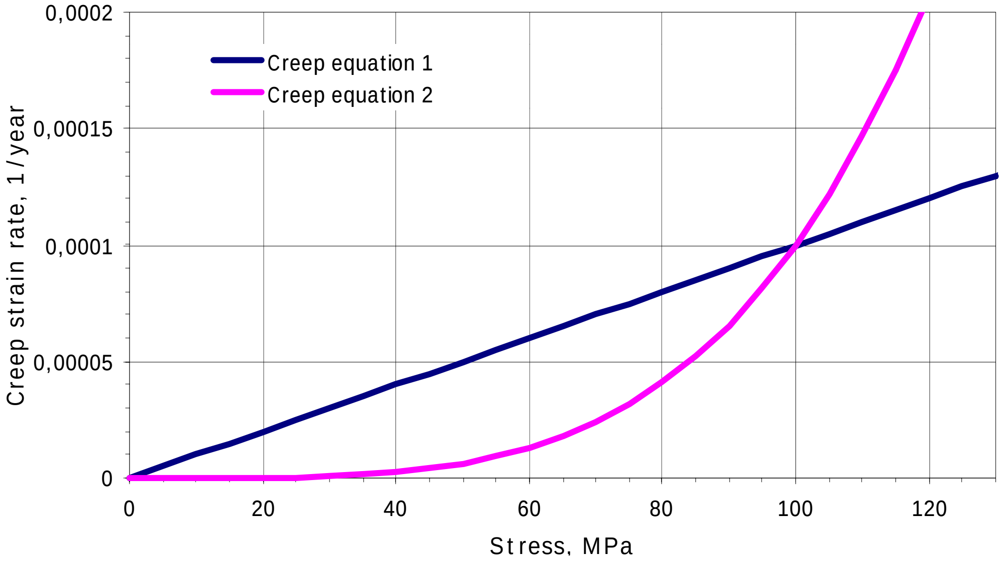


Figure 3 Creep strain rate as a function of stress.

4 Load cases

Three loading conditions are considered:

- axisymmetric outer pressure that differs between lid and cylinder
- uniform outer pressure
- side pressure on part of the canister.

Loads analysed in this report are described in *Reference 1* and listed in *Table 1*.

Cases 1 to 3 are axisymmetric loads and case 4 is a side pressure applied on half of the cylinder casing. Regions A-C refer to axisymmetric regions and region D is symmetric in the *x*-*z* plane (about the *x*-*y* plane). Creep analyses are performed for load case 1 and for a side pressure of 10 MPa (load case 4).

Table 1 Load cases. See Figure 4 and 5 for reference regions A-D.

Load case		A Lid	B Lid flange top	C Lid outer flange and cylinder	D Lid outer flange and cylinder
1	Static Creep 500 yrs	15 MPa	5 MPa	5 MPa	
2	Static	5 MPa	5 MPa	15 MPa	
3	Static	20 MPa	20 MPa	20 MPa	
4	Static Creep 1000 yrs				20 MPa 10 MPa

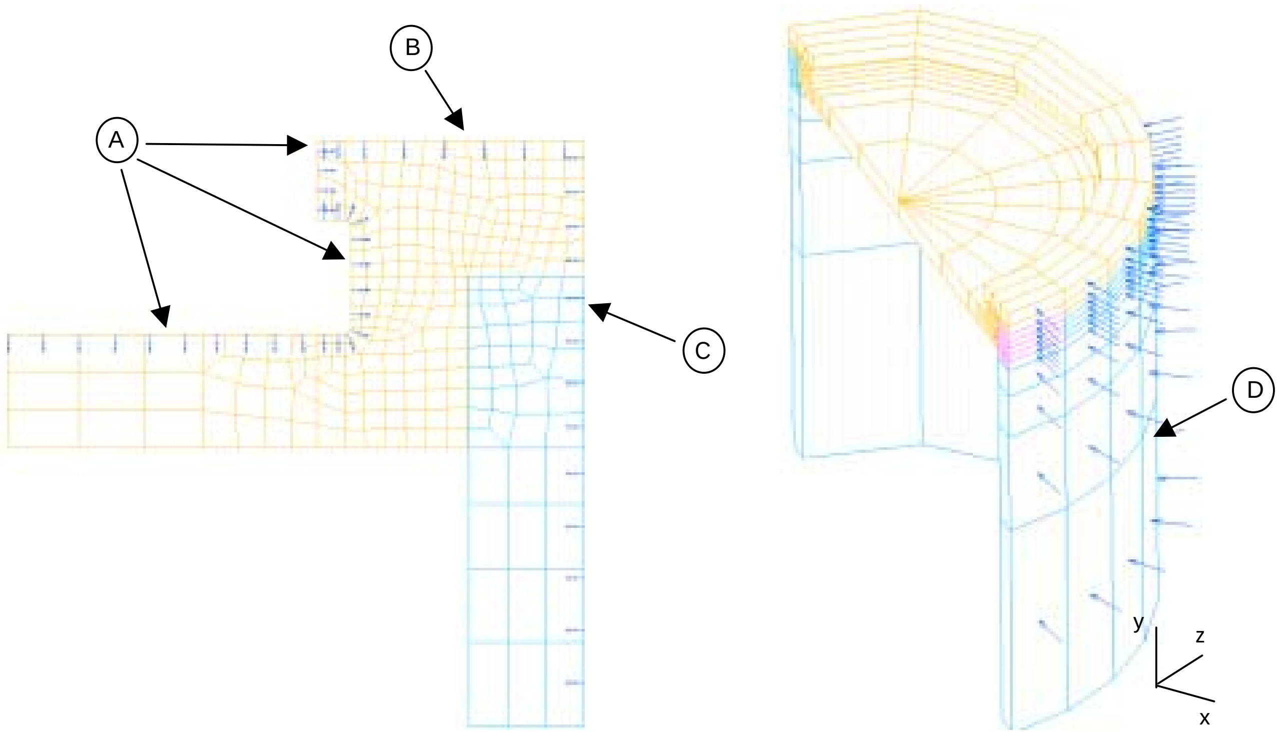


Figure 4 Outer pressure on lid and cylinder casing. Axisymmetric load cases and side load on half of the cylinder, respectively.

5 Finite Element Analysis

The finite element model (FE model) and the software used for analysis as well as the analysis procedure are described more in detail in *Reference 1*.

The models used in the current analyses are practically the same as used in previous analyses (see *Reference 1*) in order to have a tool for comparison. Small changes to the element mesh are however done due to convergence difficulties during the creep analyses. The finite element mesh is quite coarse and the analyses are intended to give an estimate of areas that may cause problems regarding stresses and deformations that appear due to the various possible cases of external pressure.

The local meshes of the FE models used in the analyses are shown in *Figure 5* and *6*.

6 Results

The analyses are performed in order to assess the sensitivity of tolerance parameters and analysis parameters on the state of stress and strain in the canister.

Maximum principal stresses are of interest since initiation and growth of cracks (stress corrosion, stable and unstable crack growth) can take place in areas where tensile principal stresses are large. The region on the outside of the cylinder in the vicinity of the lid weld is of particular interest.

Resulting maximum stresses and strains from current analyses are summarised together with analyses on previous designs (regarded as design 1 and design 2 in *Report 49-009-001/002*) in *Table 3* and *4*. The current designs will be regarded as design 3 (gap=1 mm between cylinder casing and insert) and design 4 (gap=2 mm between cylinder casing and insert), see *Table 2*.

Regions specifically analysed are the weld between lid and casing and the outside of the cylinder casing from the weld down to the level of the insert. Referenced regions are shown in *Figure 5* and *6*.

Result figures for the gap sensitivity study are shown in *Appendix A* and for the creep sensitivity study in *Appendix B*. Stresses, strains and gap distances are shown in result plots from I-DEAS and in result graphs as a function of applied load or creep time.

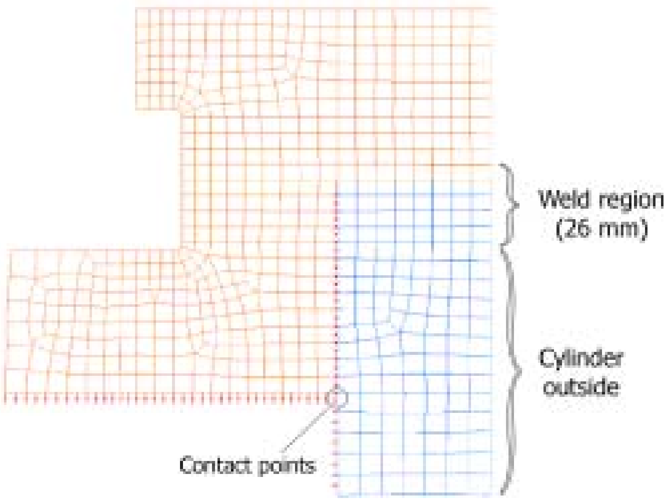


Figure 5 Elements in the lid/cylinder transition region for axisymmetric analyses (load cases 1-3). Regions specifically analysed are the weld region and the outside of the cylinder. The region referred to as the weld region includes the weld surface and root, and the region in the vicinity of the weld.

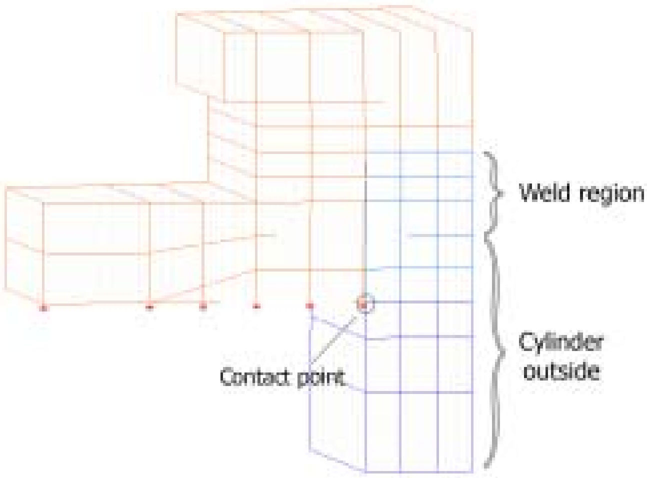


Figure 6 Elements in the lid/cylinder transition region for the 3D case (load case 4: side pressure).

6.1 Summary of results

Maximum stresses and strains for the weld and the cylinder outside region are extracted from elements in the regions denoted in *Figure 5* and *6*. Plastic strains for design 3 and 4 are only considered in the weld and cylinder outside region, while for design 1 and 2 also the lid fillet is considered. Referenced designs have the specifics listed in *Table 2*.

Table 2 Gaps in design 1-4.

	Design 1	Design 2	Design 3	Design 4
Gap between cylinder and insert (mm)	4 mm	4 mm	1 mm	2 mm
Gap between cylinder and lid (mm)	1 mm	0 mm	1 mm	1 mm

Table 3 Summary of resulting maximum tensile stresses for analysed load cases. Comparison between current analyses and analyses performed on previous designs. If no load fraction is specified, stresses appear at the final load.

Load Case	Maximum principal stress (MPa)							
	Weld				Cylinder outside			
	Design 1	Design 2	Design 3	Design 4	Design 1	Design 2	Design 3	Design 4
1 static 15/5 MPa	52	15	56	56	55	55	54	54
creep 500 yrs, n=1	4	5	3.3	3.4	2	5	-1.6	-1.3
n=4			32				53	
2 static 5/15 MPa	53	29	50	53	53	45	44	48
3 static 20 MPa	48		54	55	52		53	56
4 static 20 MPa	34		29	37	71		64	66
creep 1000 yrs, n=1	6		5	5	52		61	61
n=4			2				38	
Maximum	53	29	56	56	71	45	64	66

Table 4 Summary of resulting maximum plastic strains for analysed load cases. Comparison between current analyses and analyses performed on previous designs.

Load Case	Maximum principal strain							
	Plastic				Creep			
	Design 1	Design 2	Design 3	Design 4	Design 1	Design 2	Design 3	Design 4
1 static 15/5 MPa	2.4 (fillet)	3.5	—	—				
creep 500 yrs, n=1					2.8	2.5	0.72	0.69
n=4							0.09	
2 static 5/15 MPa	1.6 (weld inside)	3.2	—	—				
3 static 20 MPa	3.5 (weld inside)		—	—				
4 static 20 MPa	2.1		1.9	2.2				
creep 1000 yrs, n=1					5.5		5.5	5.5
n=4							0.4	
Maximum			1.9	2.2		2.5	5.5	5.5

6.2 Design parameters

Analysis results from varying the initial gap distance between the cylinder casing and the insert are shown in *Appendix A*. In comparison of the designs with different initial gap between cylinder casing and insert, marginal differences in the static stress state can be seen for load case 2-4. In these cases a gap of 2 mm yield the higher stresses in the weld and cylinder outside region. Regarding creep stresses and strains, results are accordingly.

6.3 Creep parameters

Creep analyses employing two alternative creep equations (see *Section 3*) are performed on the design where the gap between cylinder casing and insert is 1 mm (design 3). Resulting tensile stresses and creep strains from the creep sensitivity study are summarised in *Table 3* and *Table 4*.Analysis result pictures and graphs are shown in *Appendix B*.

The behaviour during creep and also the resulting stress and creep strains differ considerably between the two creep analyses. Employing the linear creep behaviour of creep equation 1 yields higher creep strains and lower stresses in the structure.

7 Conclusions

For all considered designs high principal stresses appear on the outside of the copper cylinder in the region from the weld down to the level of the lid lower edge. Altering the gap between lid and cylinder and/or between cylinder and insert only marginally affects the resulting stress state. Fitting the lid in the cylinder with zero gap relocates the peak tensile stresses from the weld further down on the cylinder. A smaller gap between the cylinder casing and the insert yield is to prefer as regards stresses in the region close to the weld and further down on the outside of the cylinder.

From the analyses employing different creep equations it can be concluded that the structure behaviour differs considerably. Thus, in order to assess the long-term effects of the loads acting on the cylinder casing, the material creep behaviour must be more closely described.

8 References

1 “Mechanical integrity of copper canister lid and cylinder,” SKI Report 2003:05, 2003.
2 “Mechanical integrity of lid and cylindrical shell for the copper canister,” PM, SKI.
3 Drawing 00001-1111, Copper cylinder, BWR serial 1, rev 00, 970819.
4 Drawing 00001-31, Copper lid, BWR serial 1, rev 00, 970819.
5 Behnaz Aghili, SKI, *Private communication*.

A Gap study

This section presents results from calculations where the gap between cylinder casing and insert is varied. Analyses are performed for all load cases when the gap is 1 mm and 2 mm, respectively.

A.1 Contact

The graphs in *Figure 7-12* show how the gap between cylinder casing and lid, and between cylinder casing and insert varies during loading for the case when the initial gap between cylinder and insert is 1 mm and 2 mm, respectively. Results are extracted from the contact elements denoted in *Figure 5* and *Figure 6*.

A.1.1 Static results

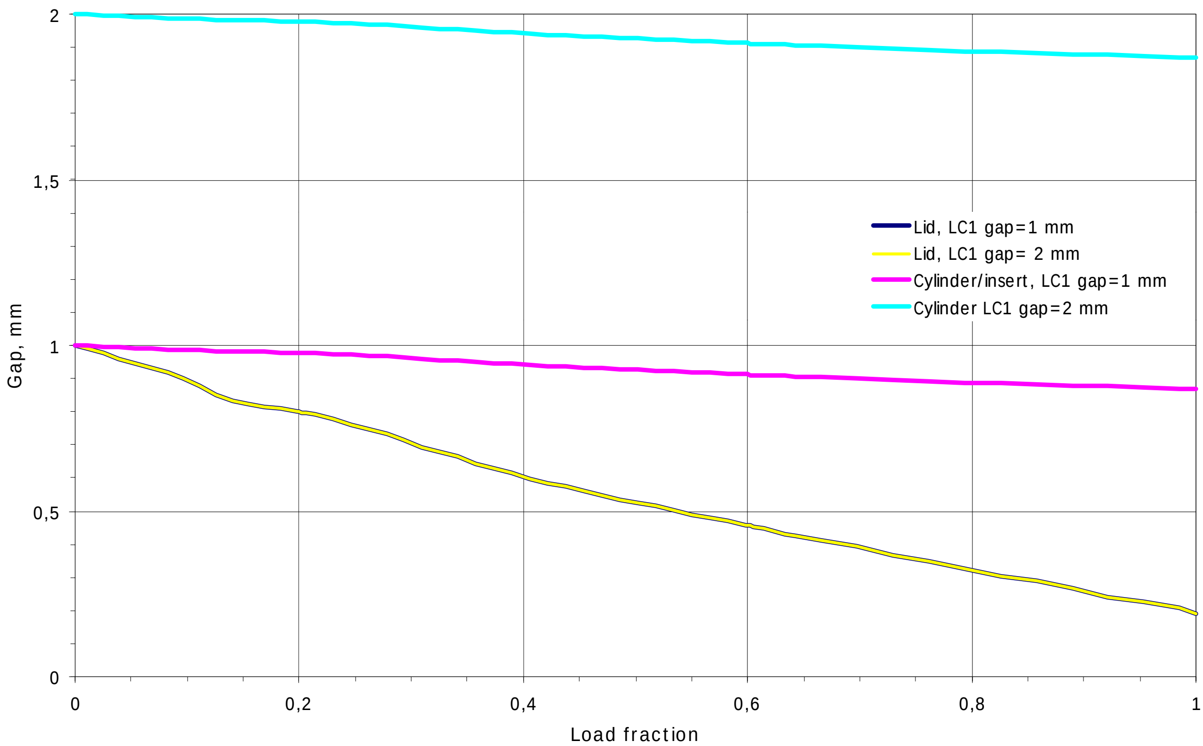


Figure 7 Gap distance, mm. Load case 1. Comparison of gap distance during loading for initial gap=1 mm and initial gap=2 mm between cylinder casing and insert.

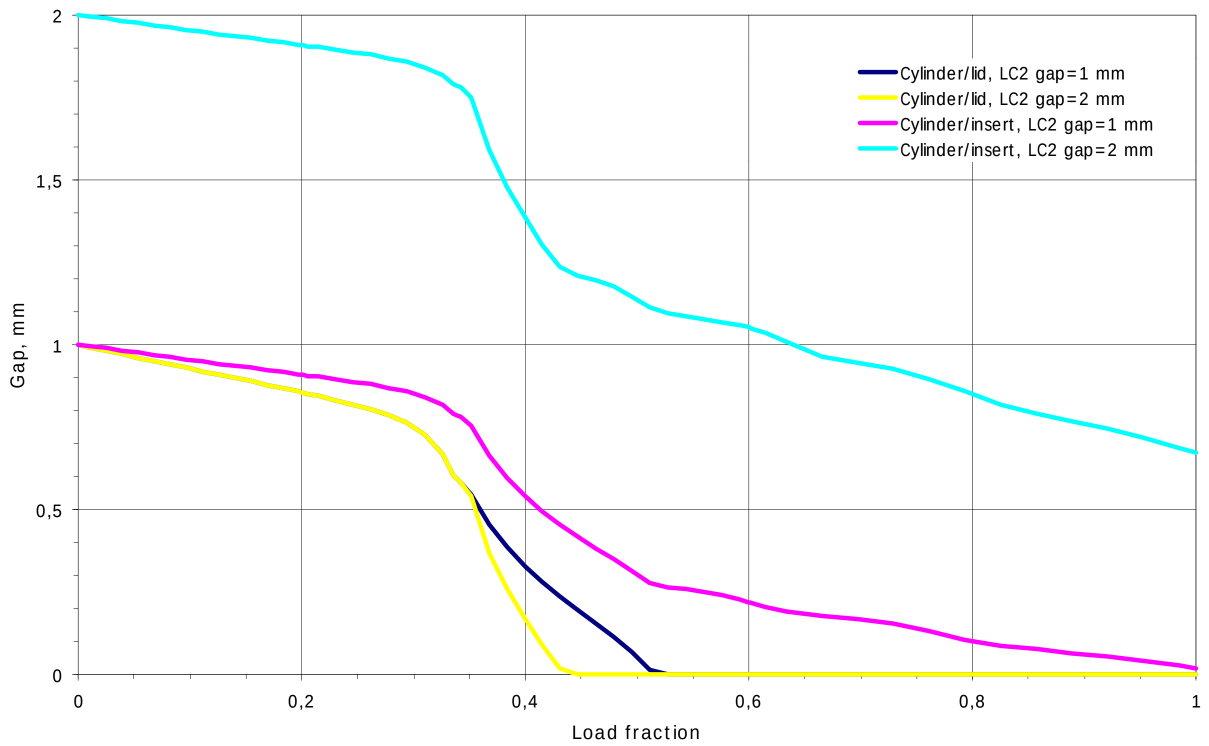


Figure 8 Gap distance, mm. Load case 2. Comparison of gap distance during loading for initial gap=1 mm and initial gap=2 mm between cylinder casing and insert.

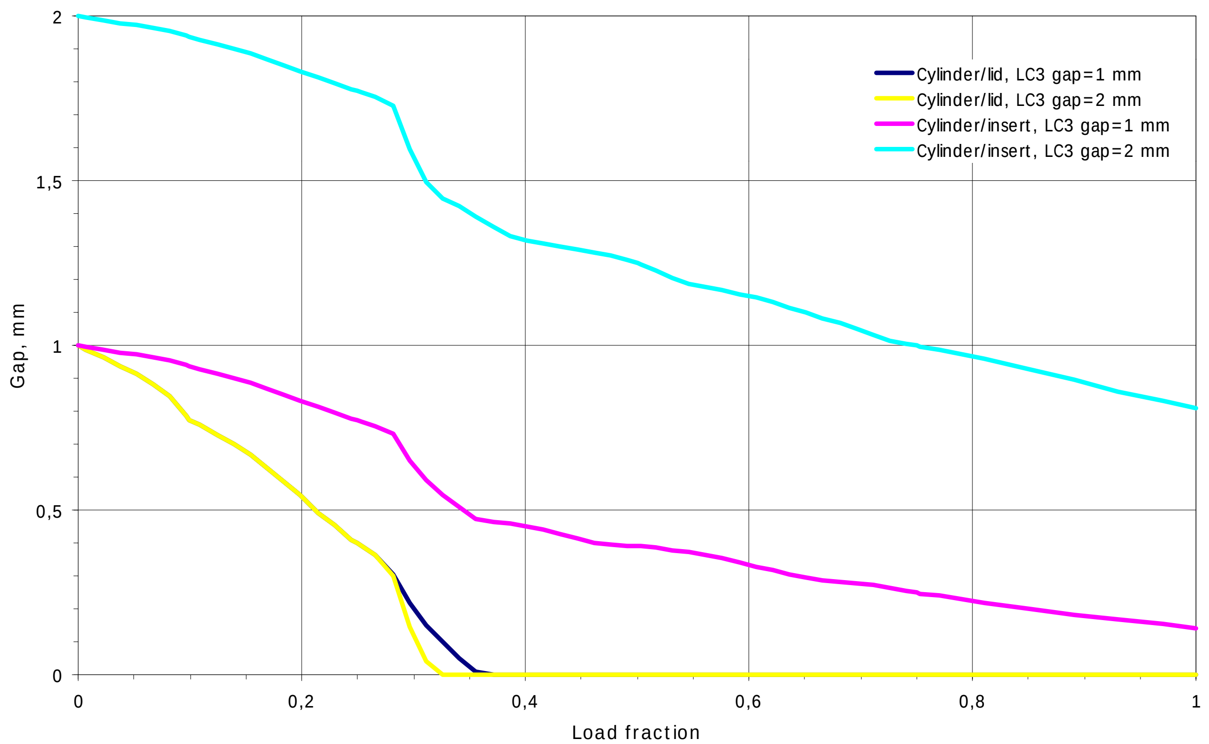


Figure 9 Gap distance, mm. Load case 3. Comparison of gap distance during loading for initial gap=1 mm and initial gap=2 mm between cylinder casing and insert.

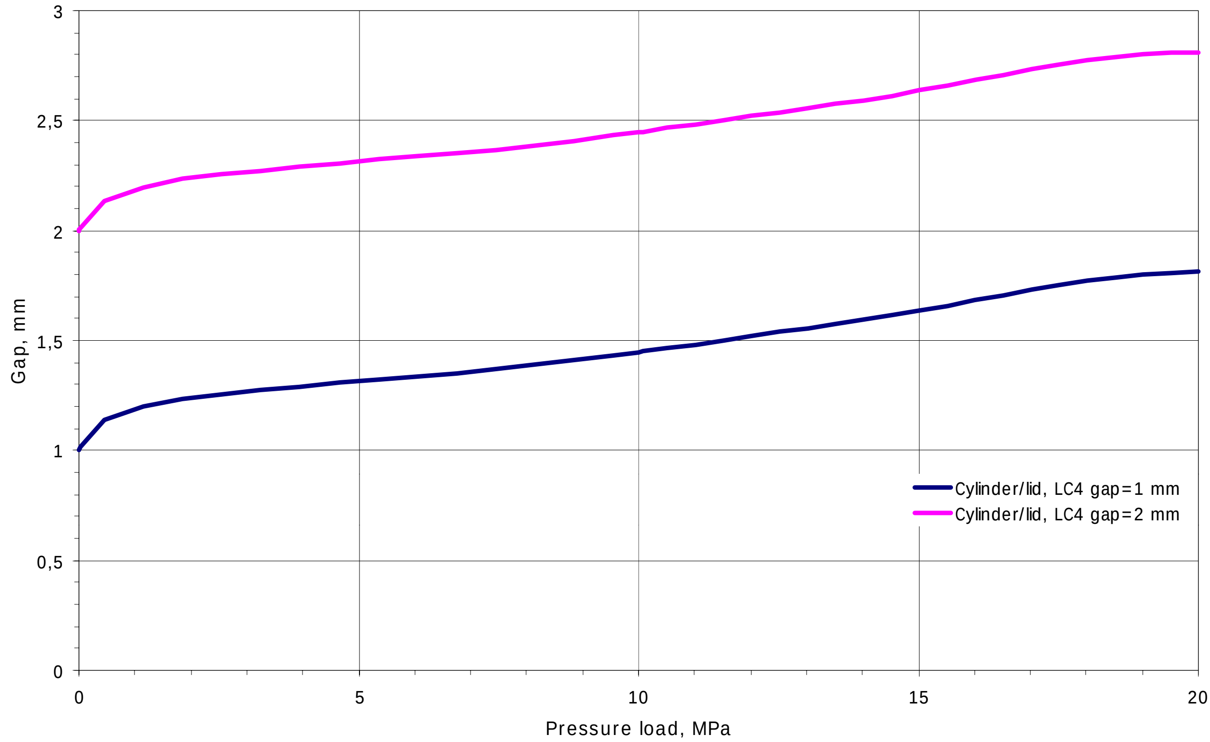


Figure 10 Gap distance, mm. Load case 4. Comparison of gap distance during loading for initial gap=1 mm and initial gap=2 mm between cylinder casing and insert.

A.1.2 Creep results

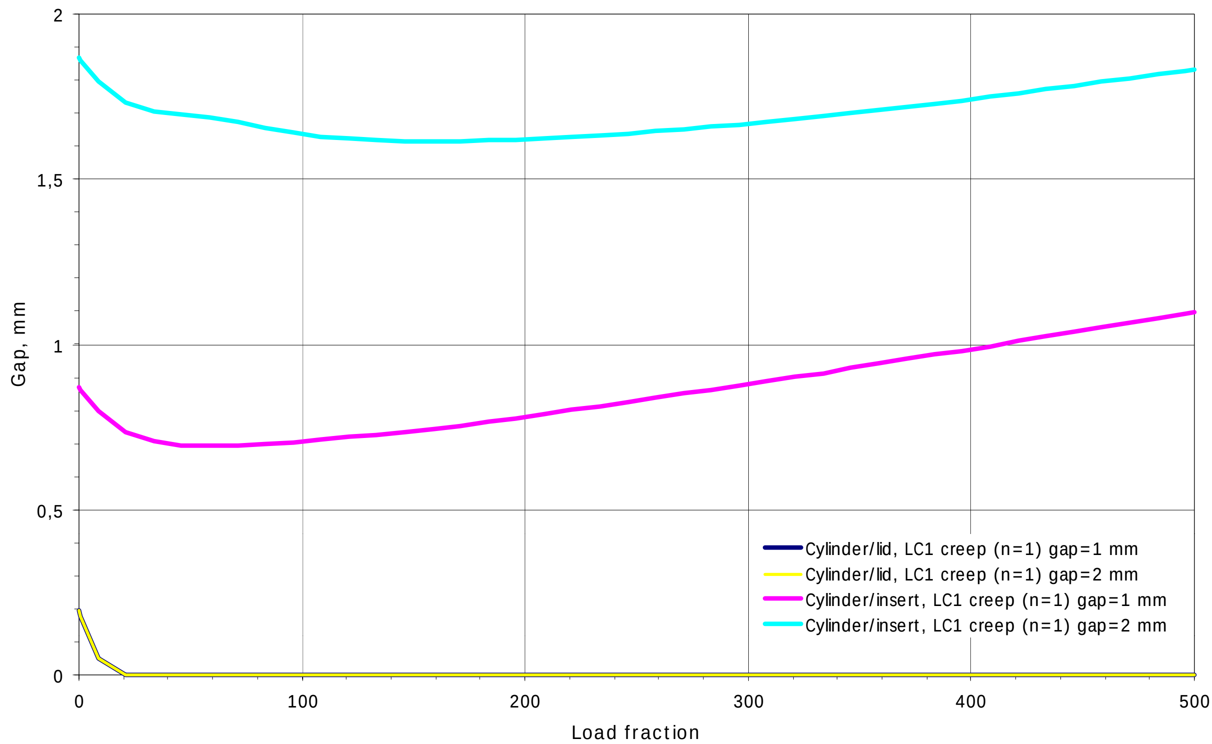


Figure 11 Gap distance, mm. Load case 1 creep 500 years. Comparison of gap distance during creep for initial gap=1 mm and initial gap=2 mm between cylinder casing and insert.

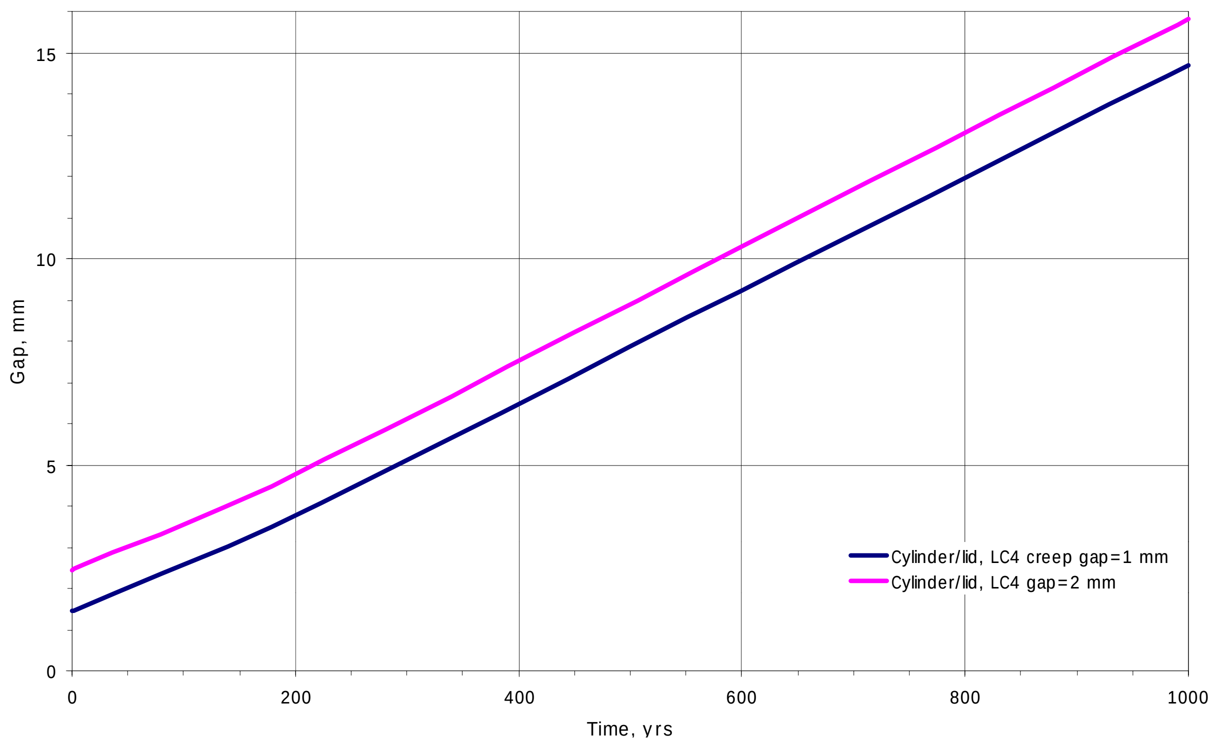


Figure 12 Gap distance, mm. Load case 4 creep 1000 years. Comparison of gap distance during creep for initial gap=1 mm and initial gap=2 mm between cylinder casing and insert.

A.2 Static results

A.2.1 Stress

Figure 13-24 show resulting maximum principal stresses for load case 1-4 where the gap between the cylinder casing and insert is 1 mm and 2 mm, respectively.

Load case 1 — Lid 15 MPa, cylinder 5 MPa

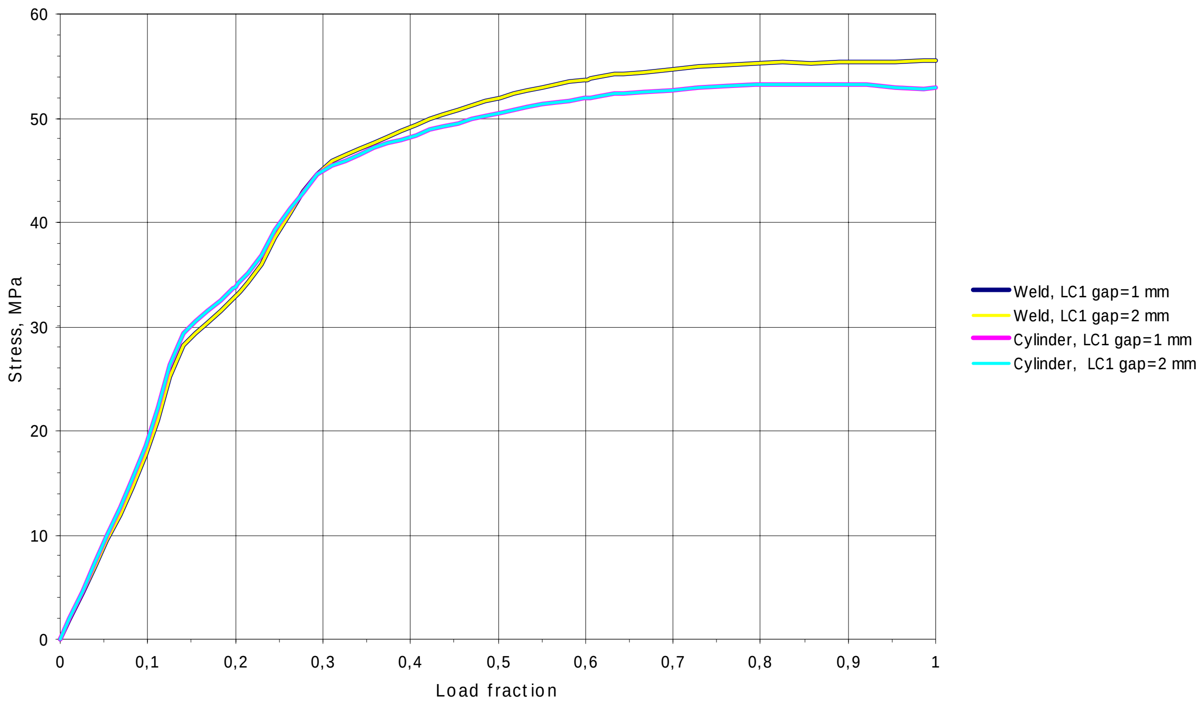


Figure 13 Max principal stress during loading, MPa. Load case 1. Comparison of stress in the weld and cylinder outside region for gap=1 mm and gap=2 mm between cylinder casing and insert.

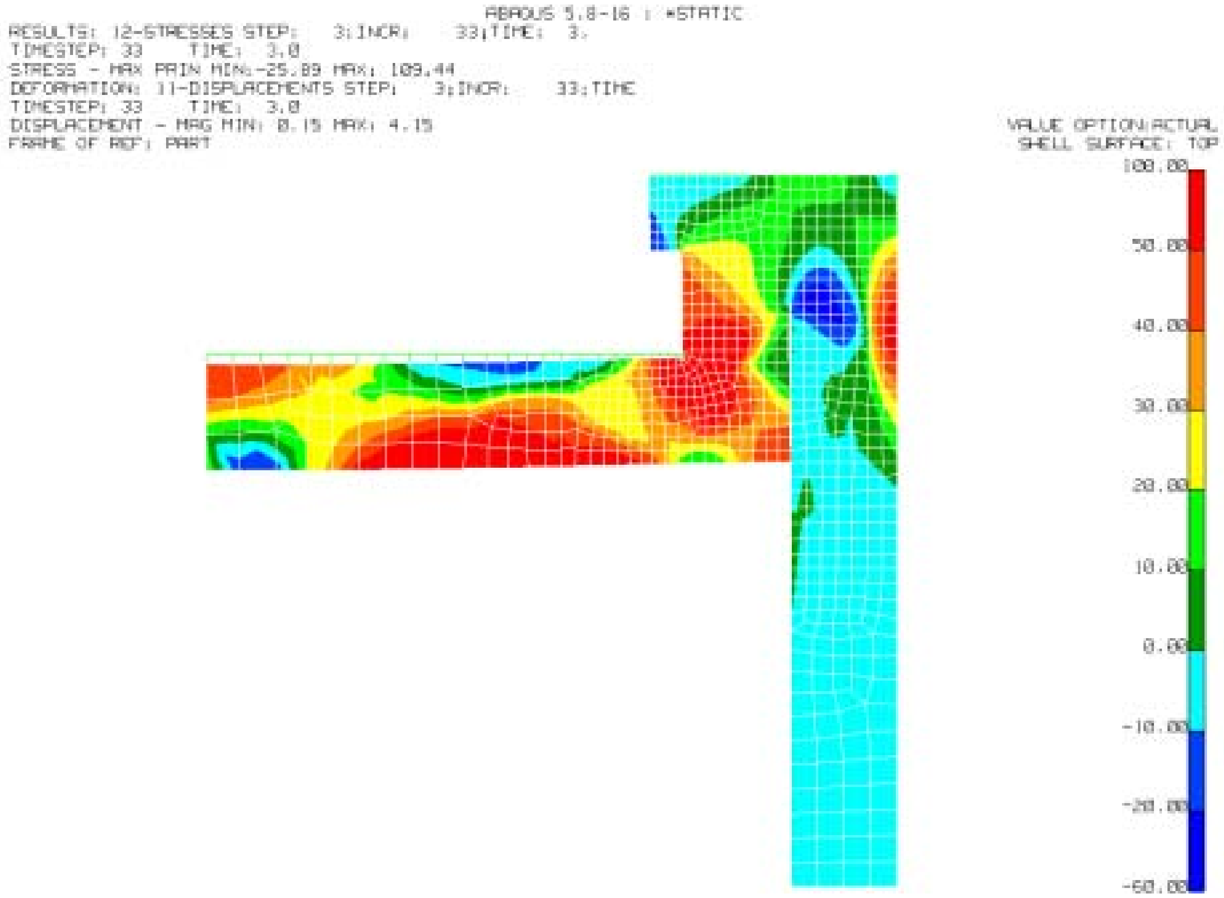


Figure 14 Max principal stress, MPa. Load case 1 for a gap=1 mm between cylinder casing and insert.

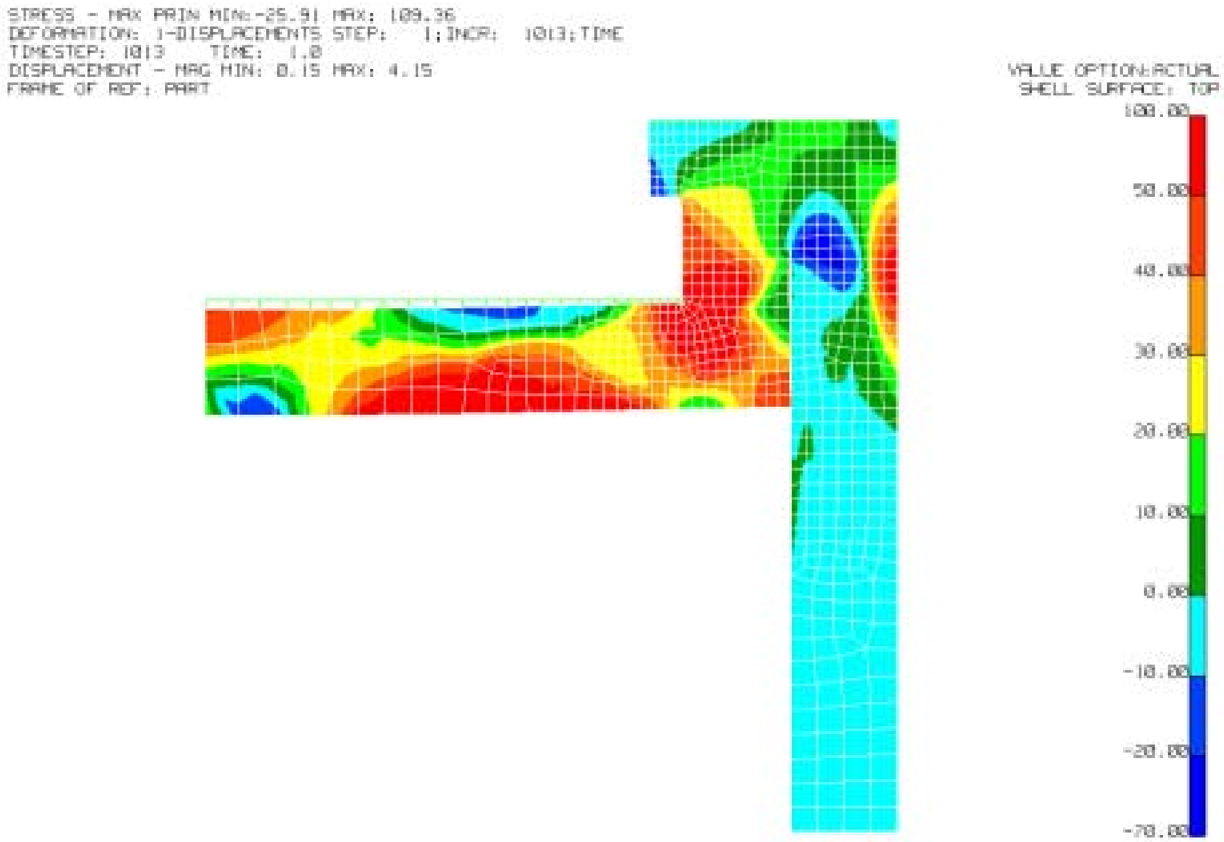


Figure 15 Max principal stress, MPa. Load case 1 for a gap=2mm between cylinder casing and insert.

Load case 2 — Lid 5 MPa, cylinder 15 MPa

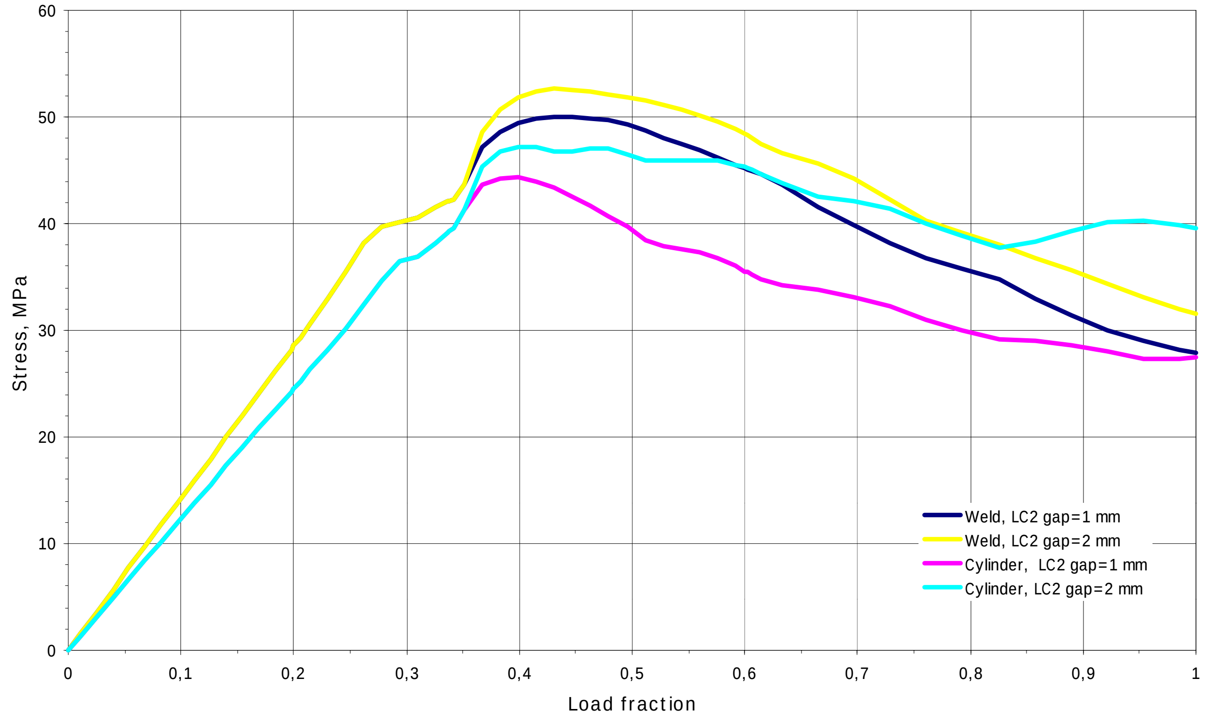


Figure 16 Max principal stress during loading, MPa. Load case 2. Comparison of stress in the weld and cylinder outside region for gap=1 mm and gap=2 mm between cylinder casing and insert.

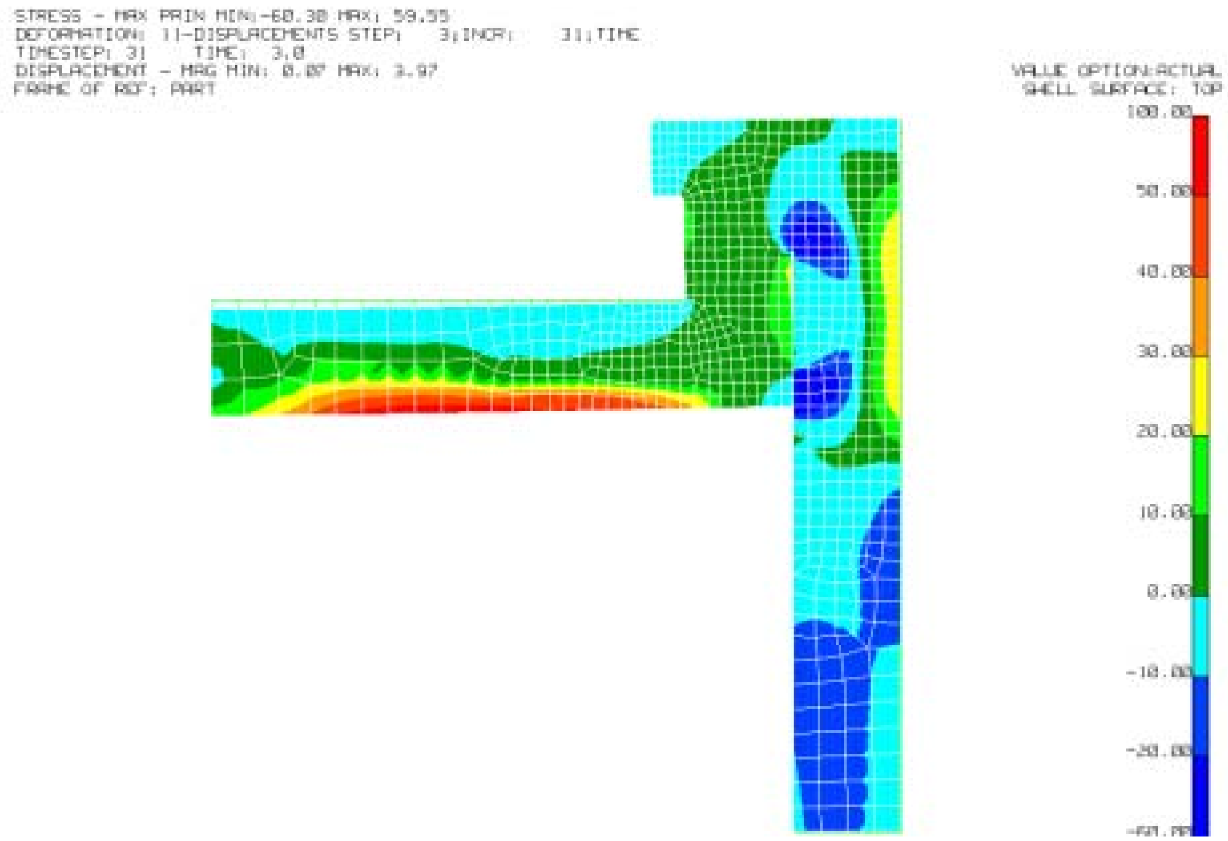


Figure 17 Max principal stress, MPa. Load case 2 for a gap=1 mm between cylinder casing and insert.

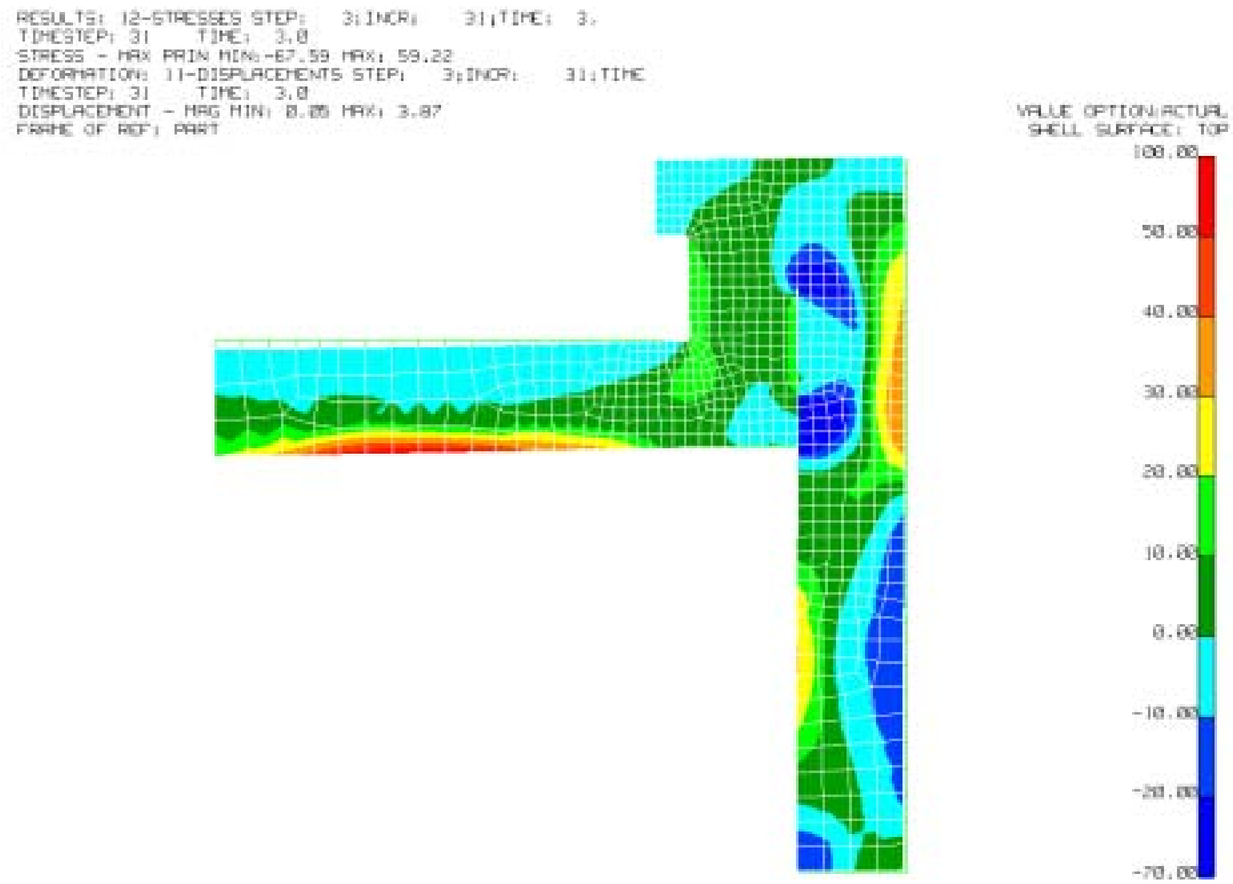


Figure 18 Max principal stress, MPa. Load case 2 for a gap=2mm between cylinder casing and insert.

Load case 3 — Lid and cylinder 20 MPa

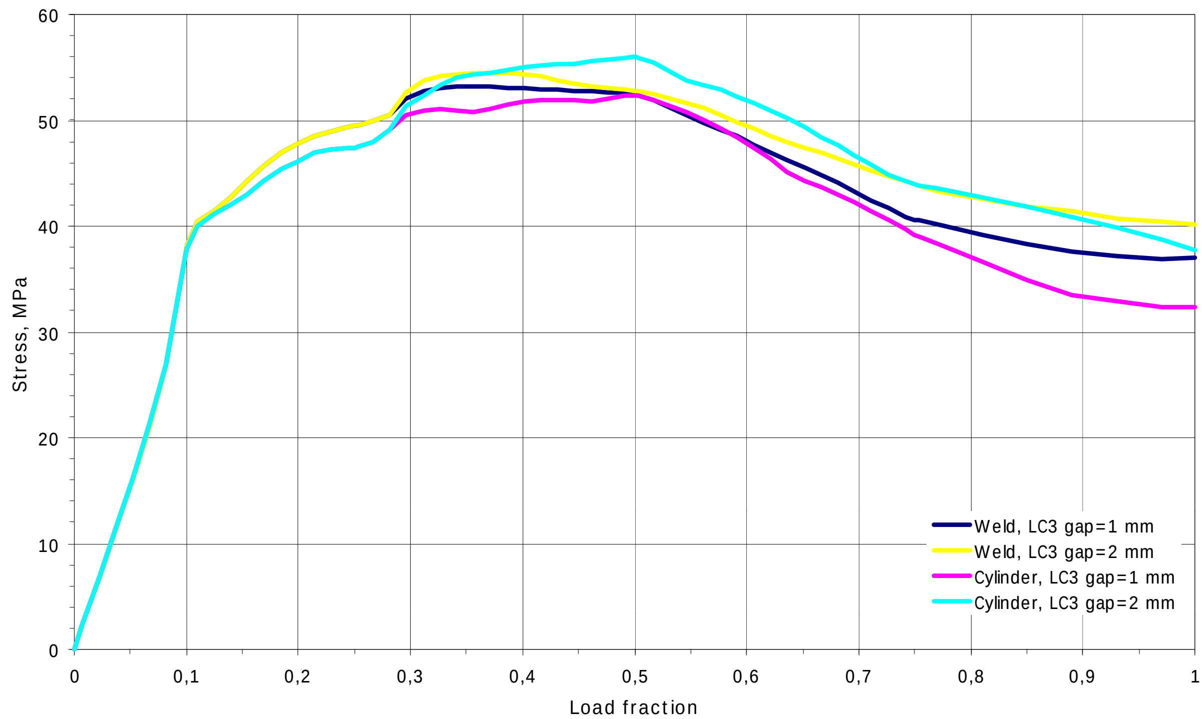


Figure 19 Max principal stress during loading, MPa. Load case 3. Comparison of stress in the weld and cylinder outside region for gap=1 mm and gap=2 mm between cylinder casing and insert.

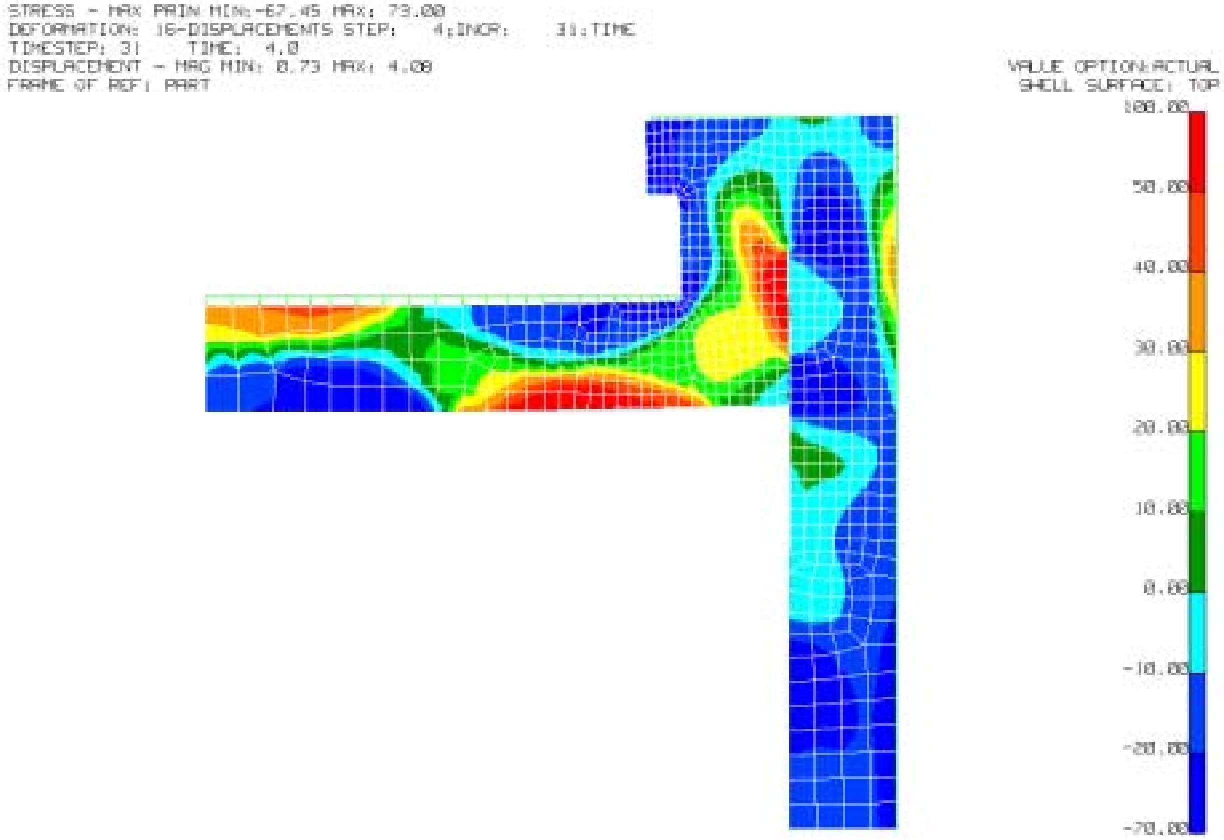


Figure 20 Max principal stress, MPa. Load case 3 for a gap=1 mm between cylinder casing and insert.

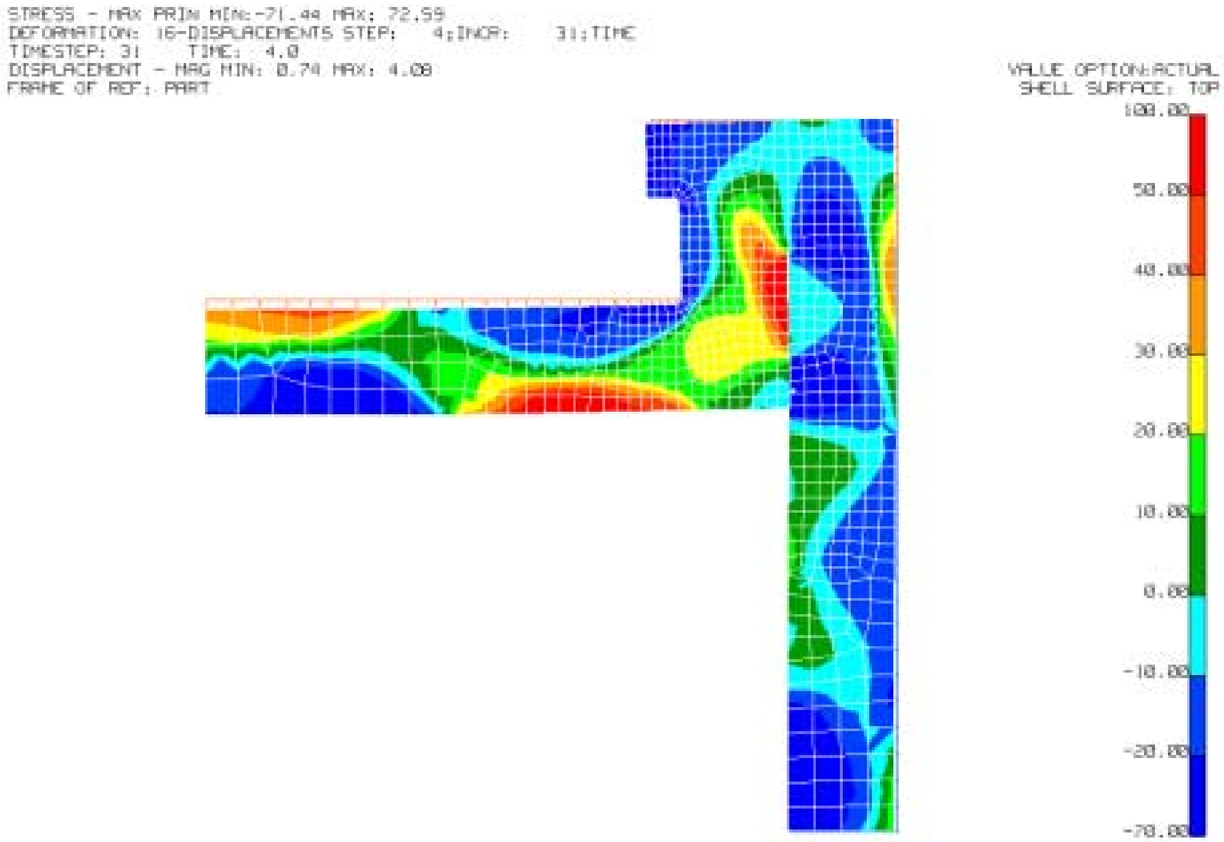


Figure 21 Max principal stress, MPa. Load case 3 for a gap=2mm between cylinder casing and insert.

Load case 4 — Side load 20 MPa

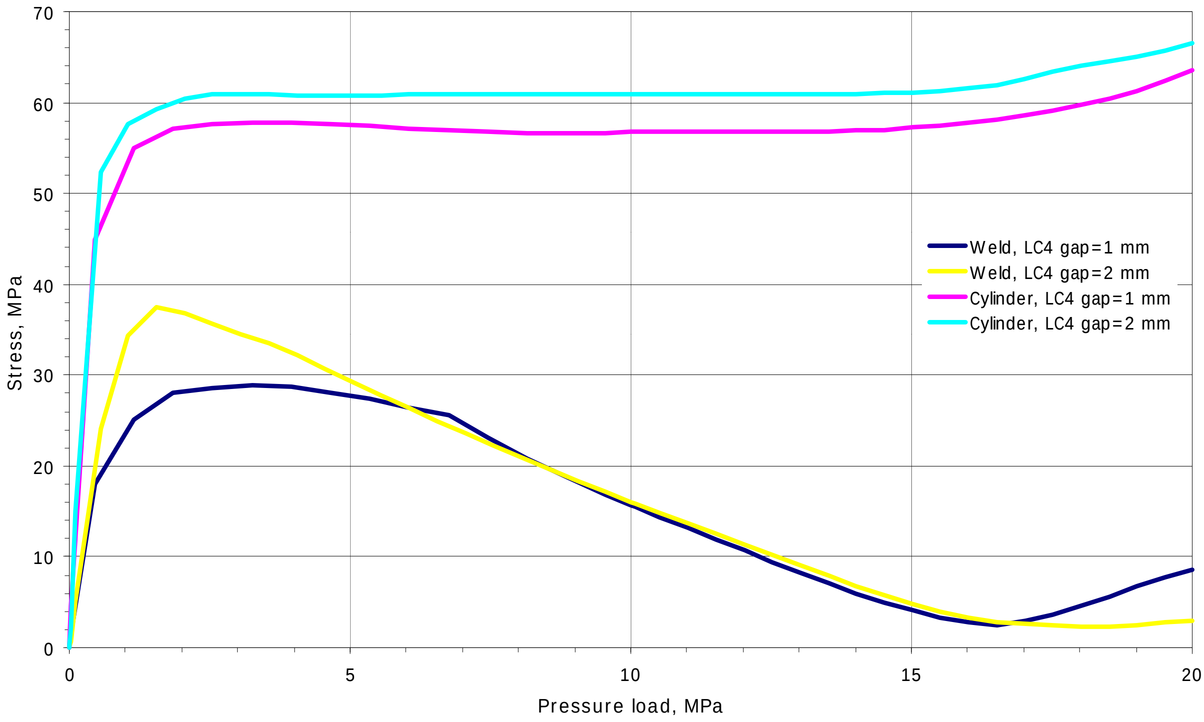
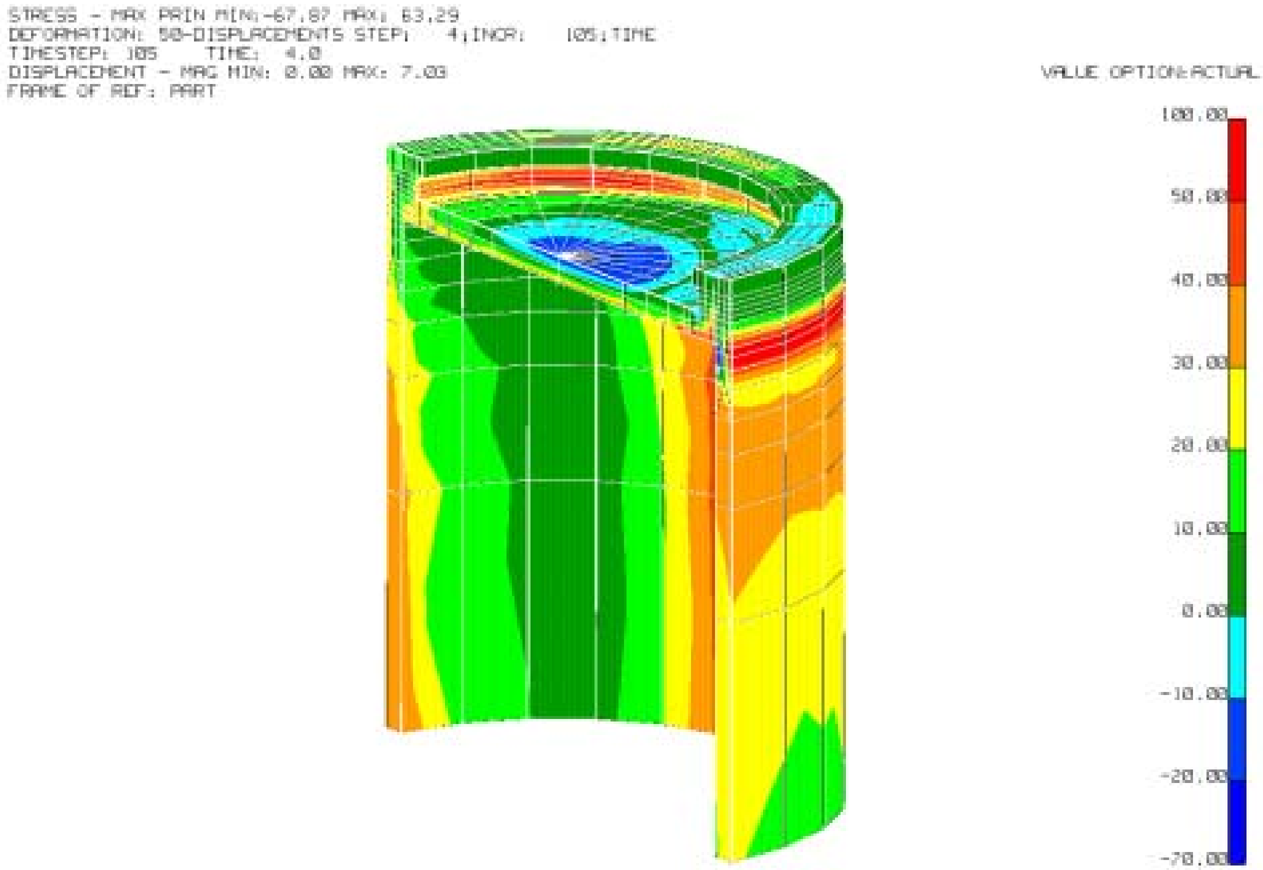


Figure 22 Max principal stress during loading, MPa. Load case 4. Comparison of stress in the weld and cylinder outside region for gap=1 mm and gap=2 mm between cylinder casing and insert.



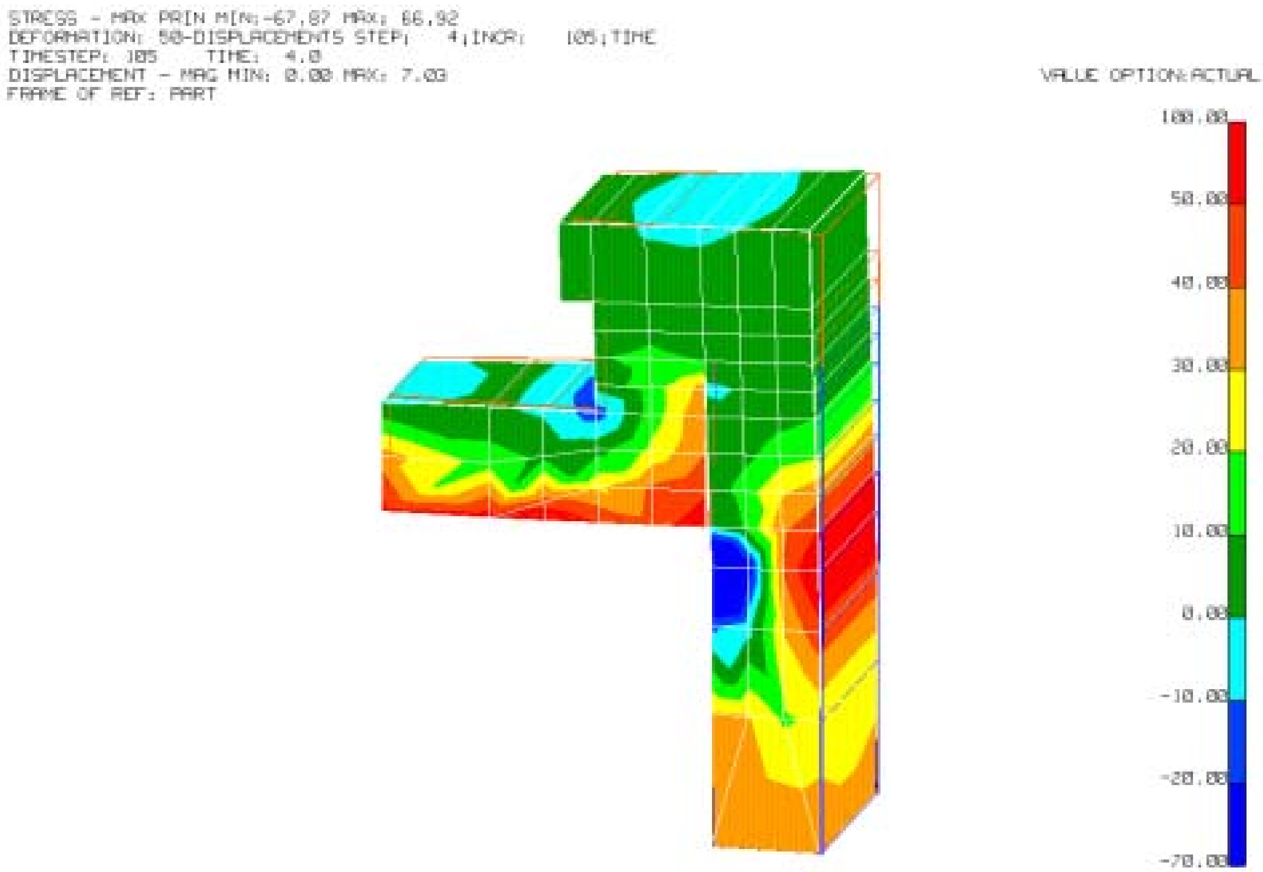


Figure 23 Max principal stress, MPa. Load case 4 for a gap=1 mm between cylinder casing and insert.

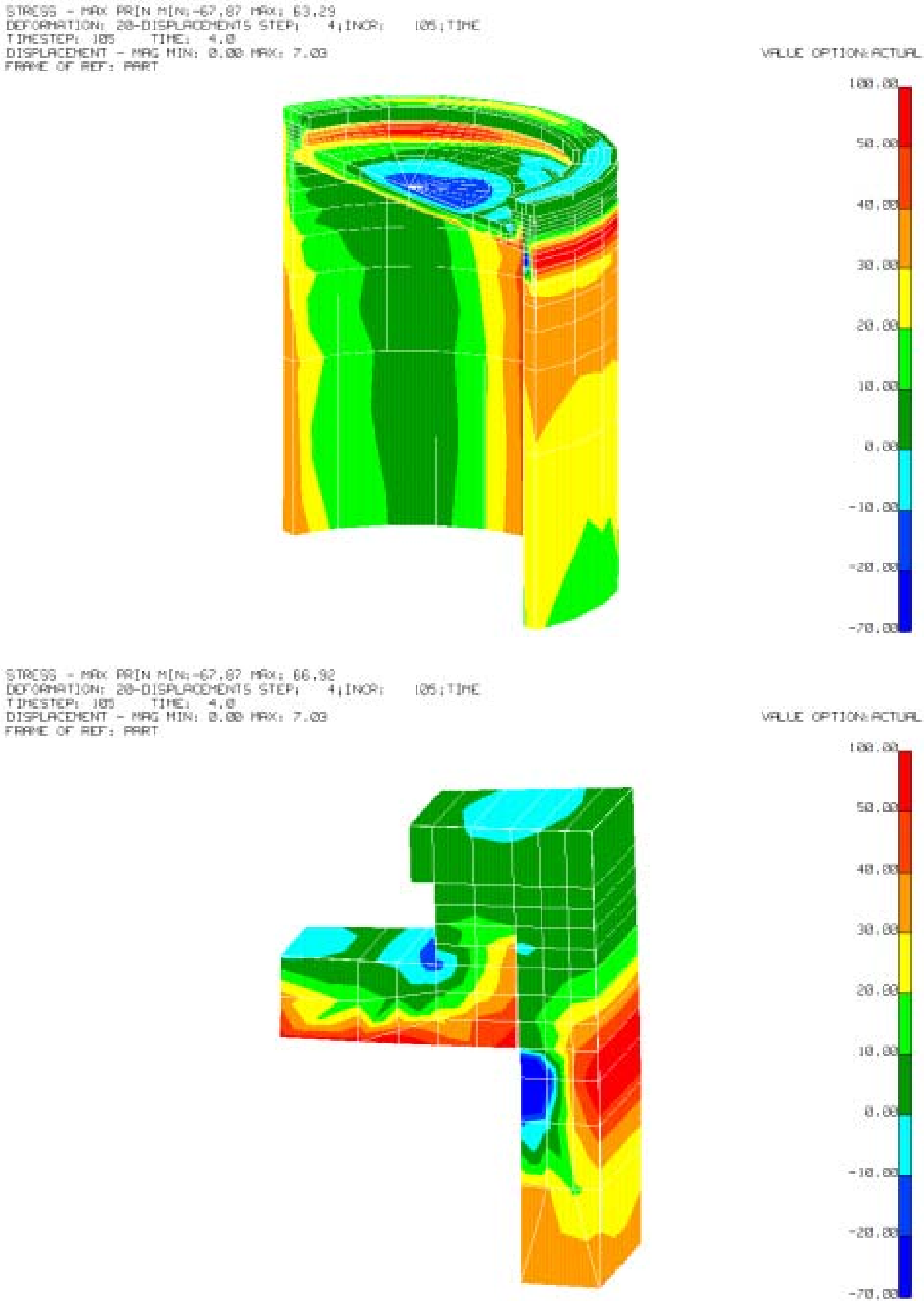


Figure 24 Max principal stress, MPa. Load case 4 for a gap=2mm between cylinder casing and insert.

A.2.2 Plastic strain

Figure 25-27 show resulting maximum principal stresses for load case 4 where the gap between the cylinder casing and insert is 1 mm and 2 mm, respectively. For load cases 1-3 no plastic strains appear on the outside of the cylinder.

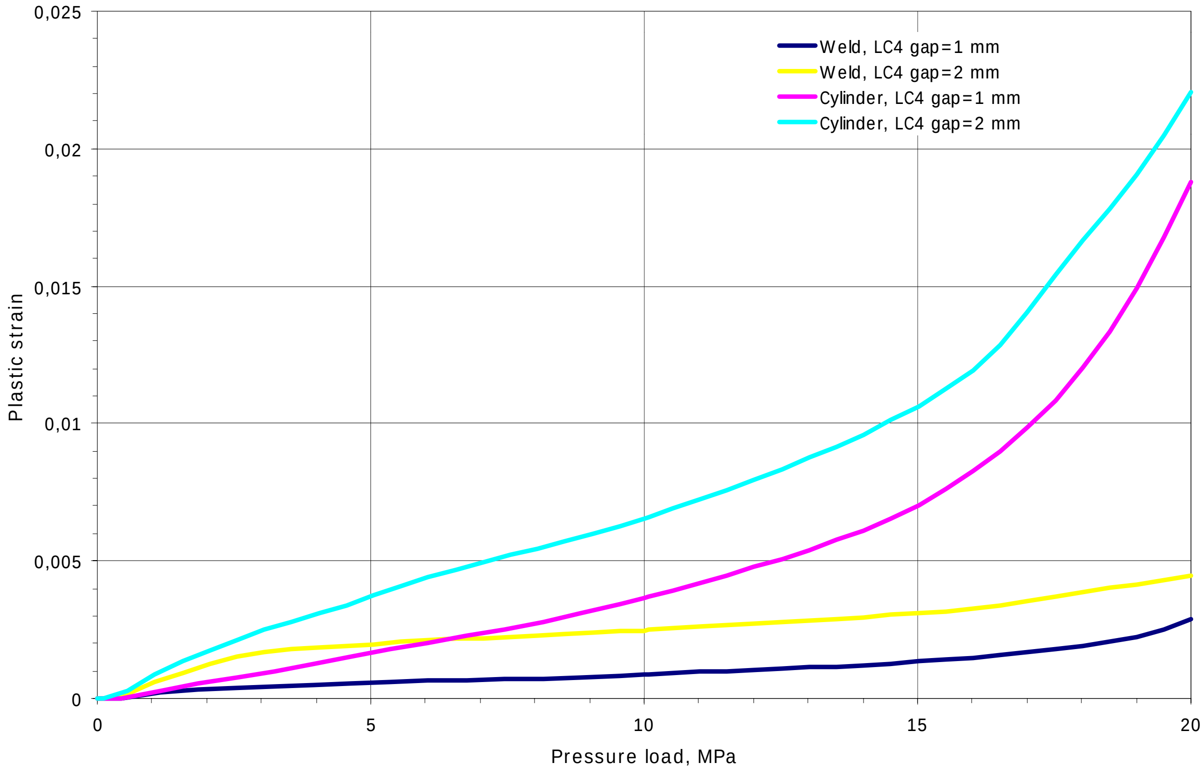


Figure 25 Max principal plastic strain during loading. Load case 4. Comparison of strain in the weld and cylinder outside region for gap=1 mm and gap=2 mm between cylinder casing and insert.

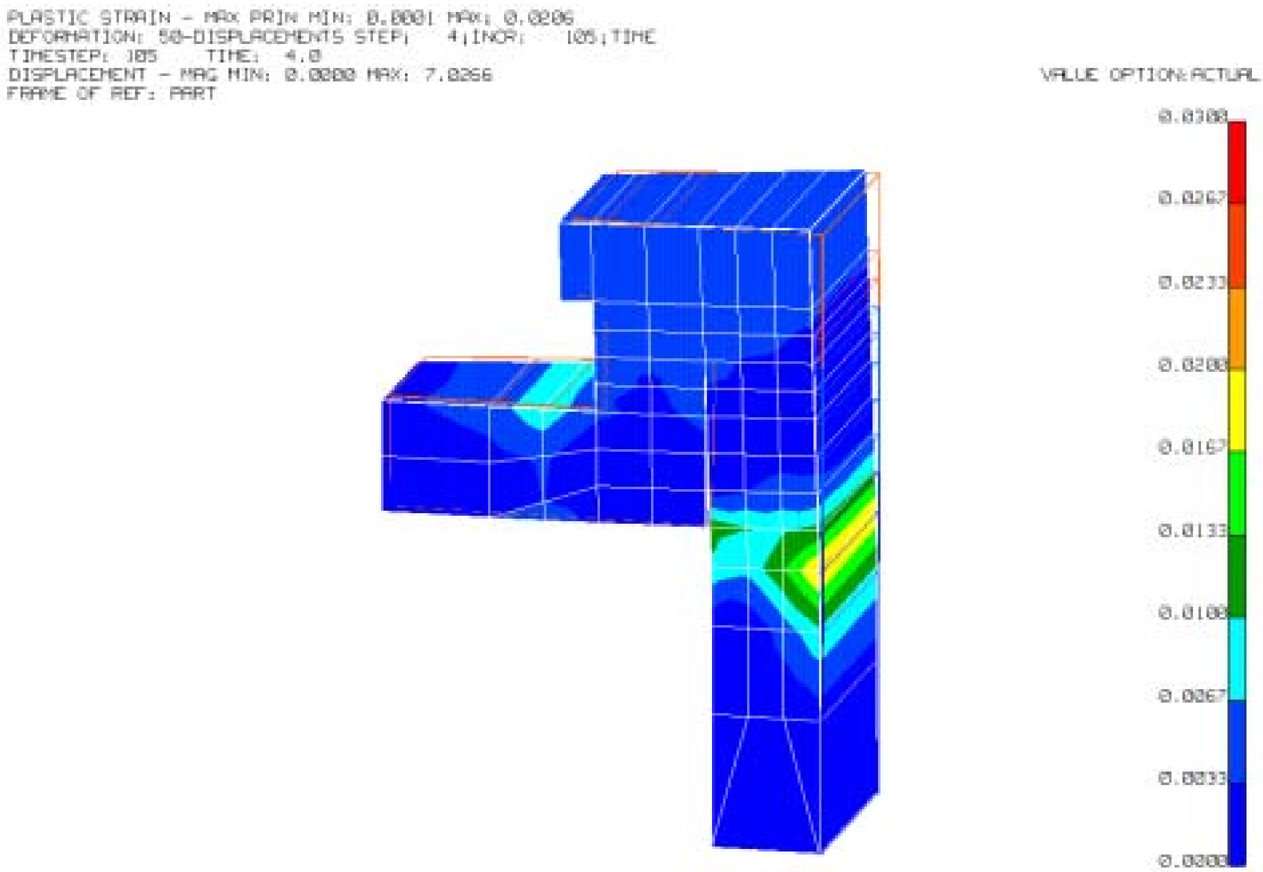


Figure 26 Max principal plastic strain. Load case 4 for a gap=1 mm between cylinder casing and insert.

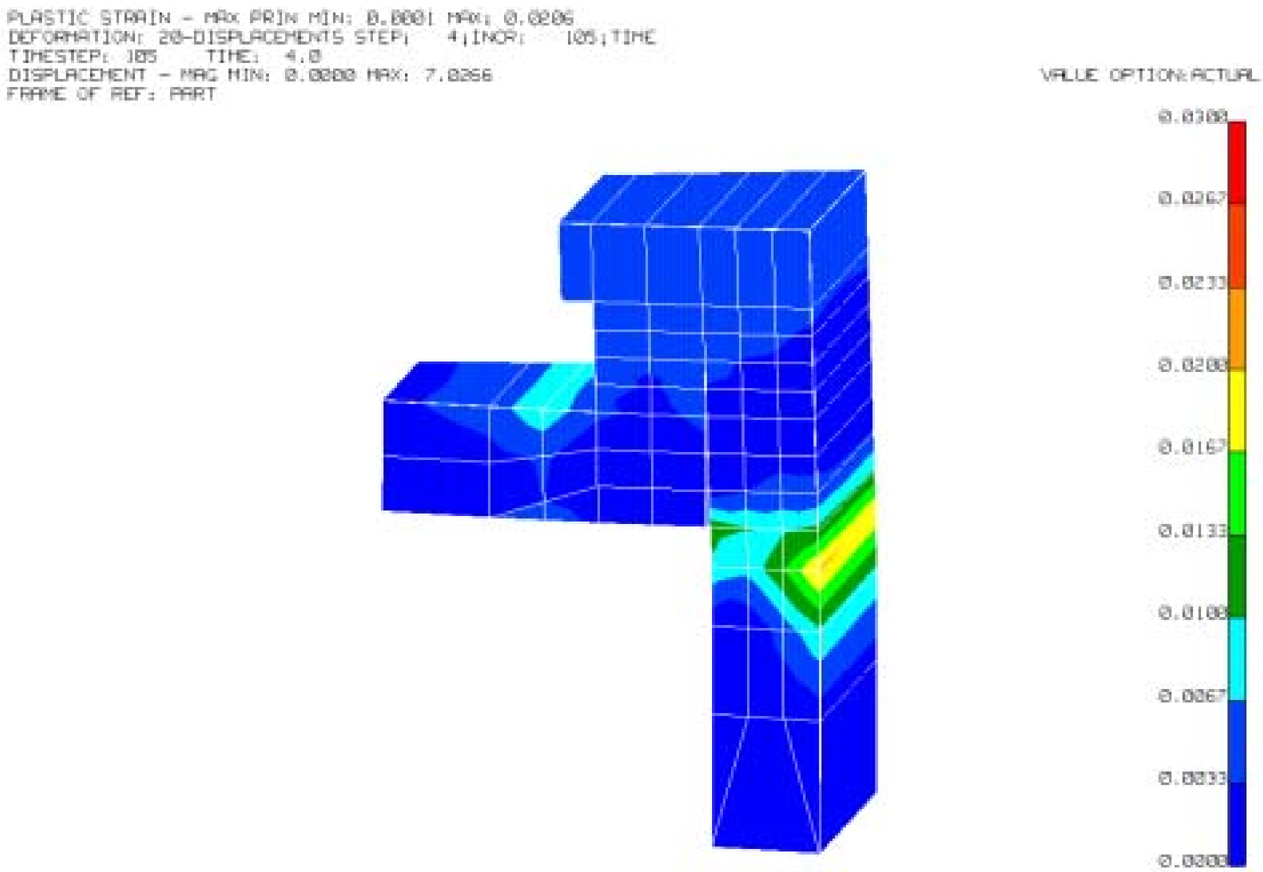


Figure 27 Max principal plastic strain. Load case 4 for a gap=2mm between cylinder casing and insert.

A.3 Creep results

Creep analyses are performed for load cases 1 and 4. *Figure 28-39* show resulting maximum principal stresses and creep strains for a gap of 1 mm and 2 mm, respectively, between the cylinder casing and the cast iron insert.

A.3.1 Stress

Load case 1 — Lid 15 MPa, cylinder 5 MPa

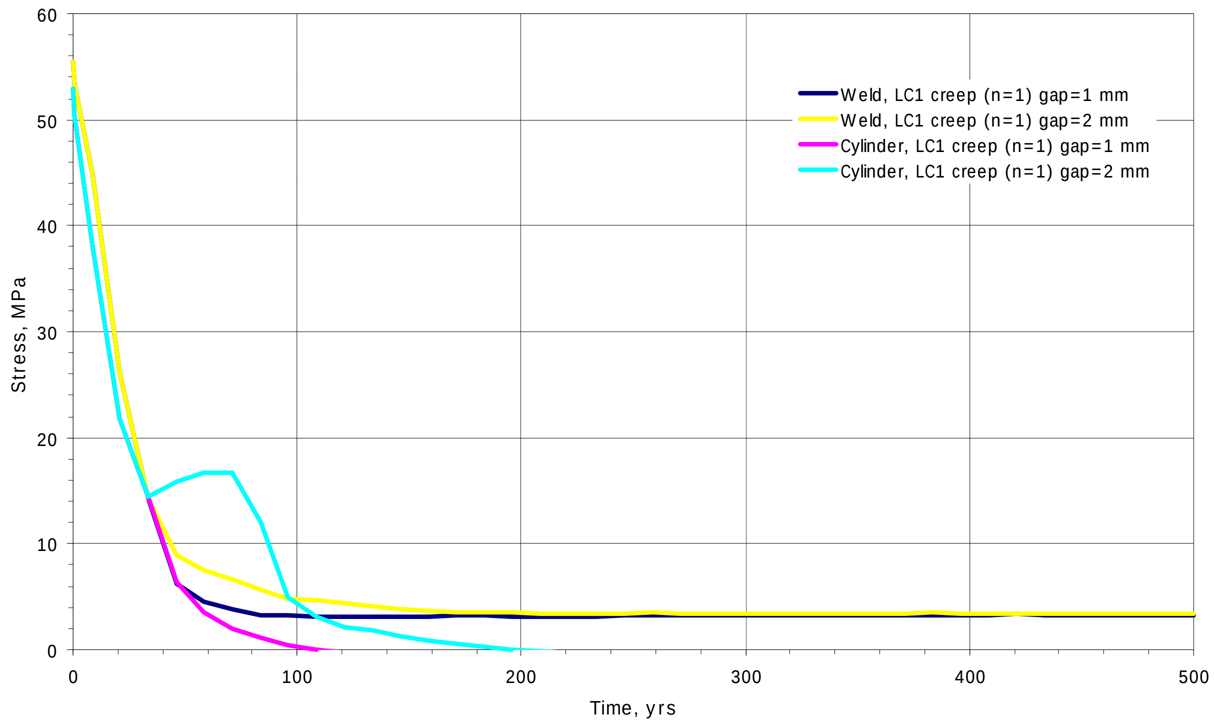


Figure 28 Max principal stress during creep 500 years (MPa). Load case 1. Comparison of stresses in the weld and cylinder outside region for gap=1 mm and gap=2 mm between cylinder casing and insert.

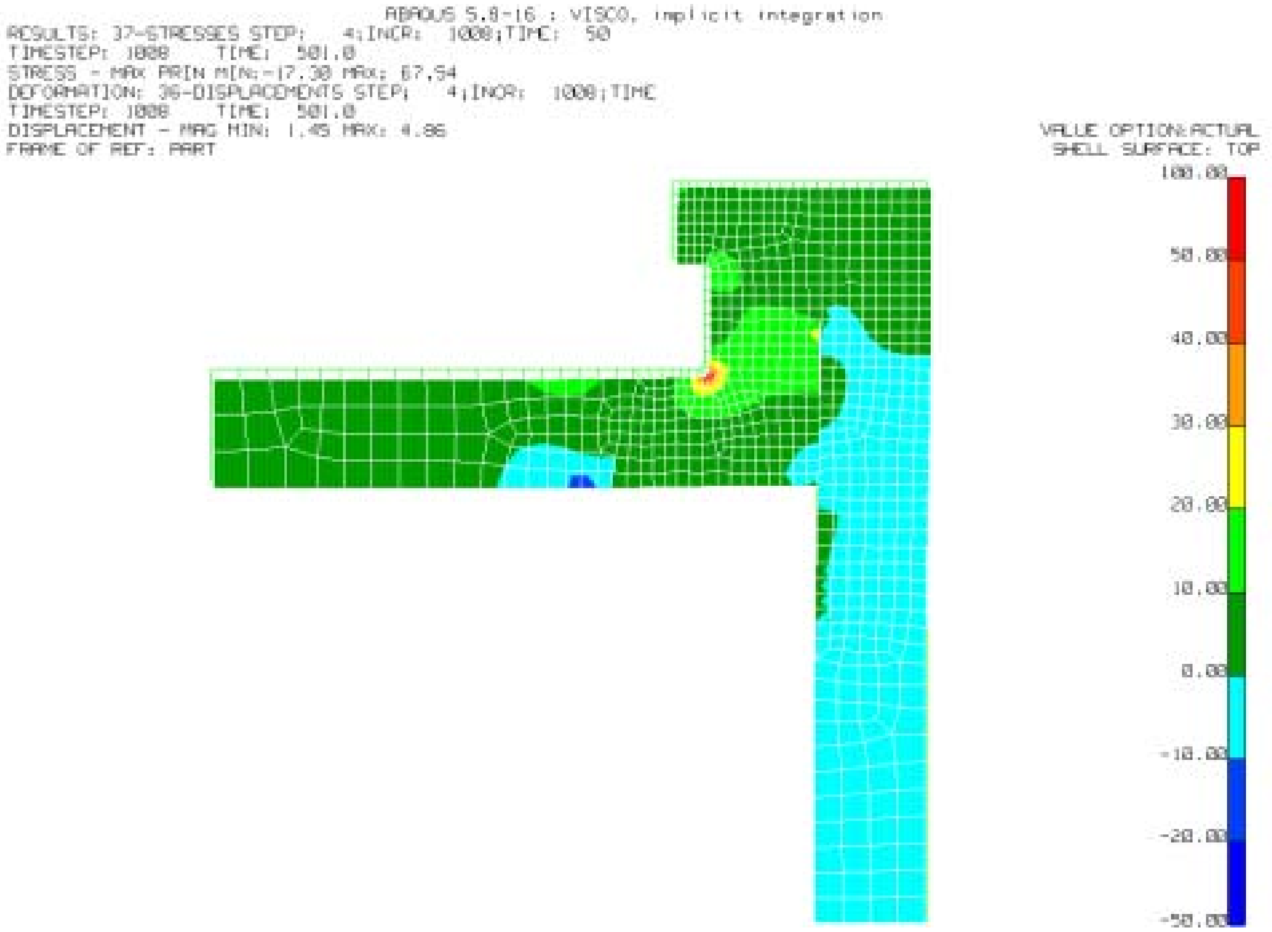


Figure 29 Max principal stress, MPa. Load case 1 creep 500 years. Gap=1 mm between cylinder casing and insert.

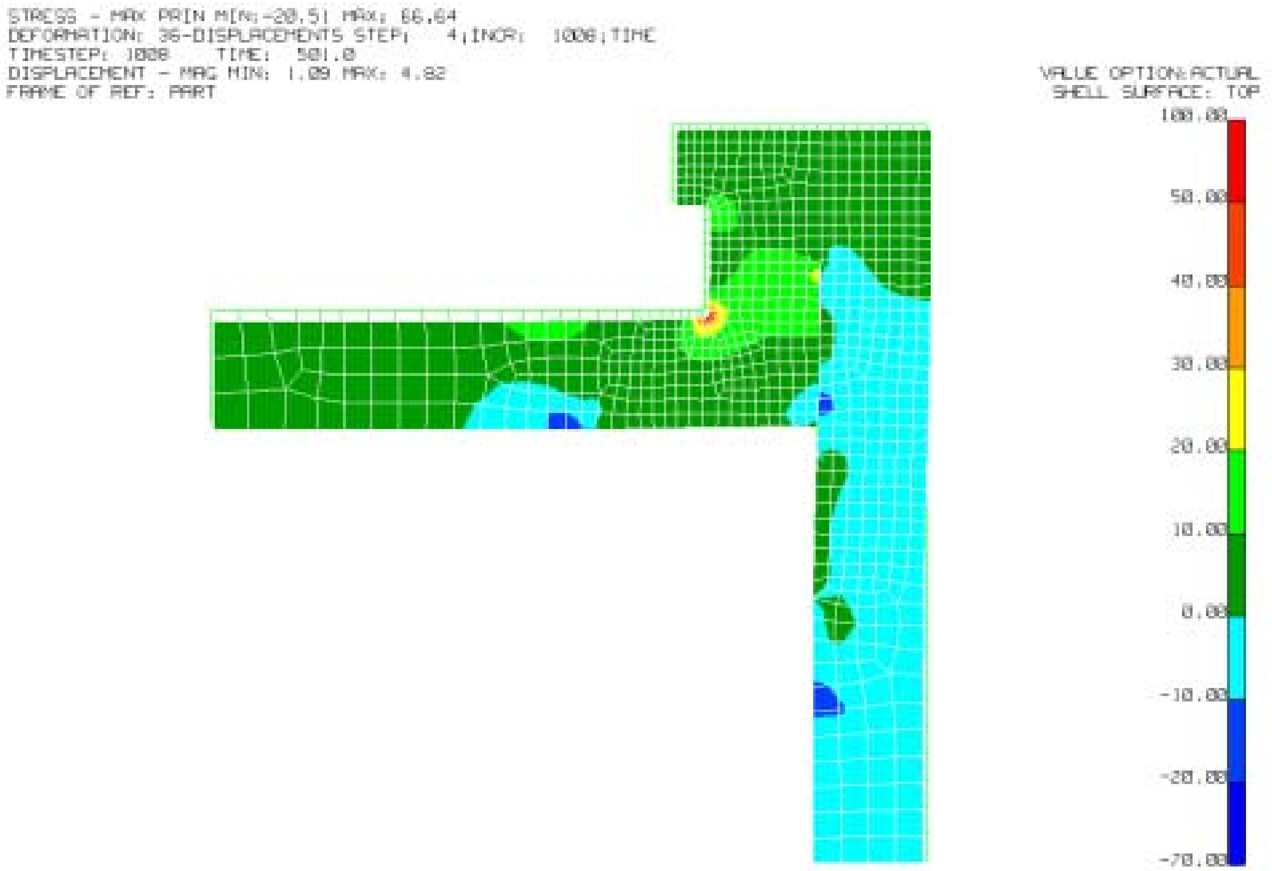


Figure 30 Max principal stress, MPa. Load case 1 creep 500 years. Gap=2mm between cylinder casing and insert.

Load case 1 — Side load 20 MPa

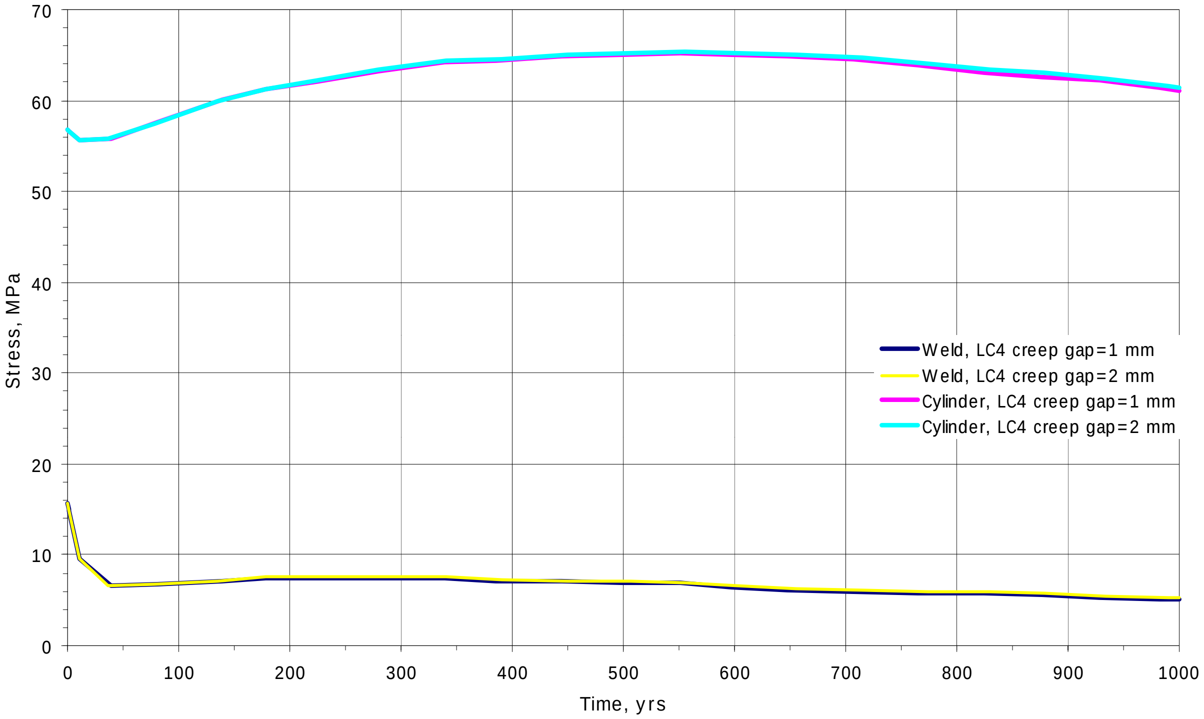


Figure 31 Max principal stress during creep 1000 years (MPa). Load case 4 10 MPa. Comparison of stresses in the weld and cylinder outside region for gap=1 mm and gap=2 mm between cylinder casing and insert.

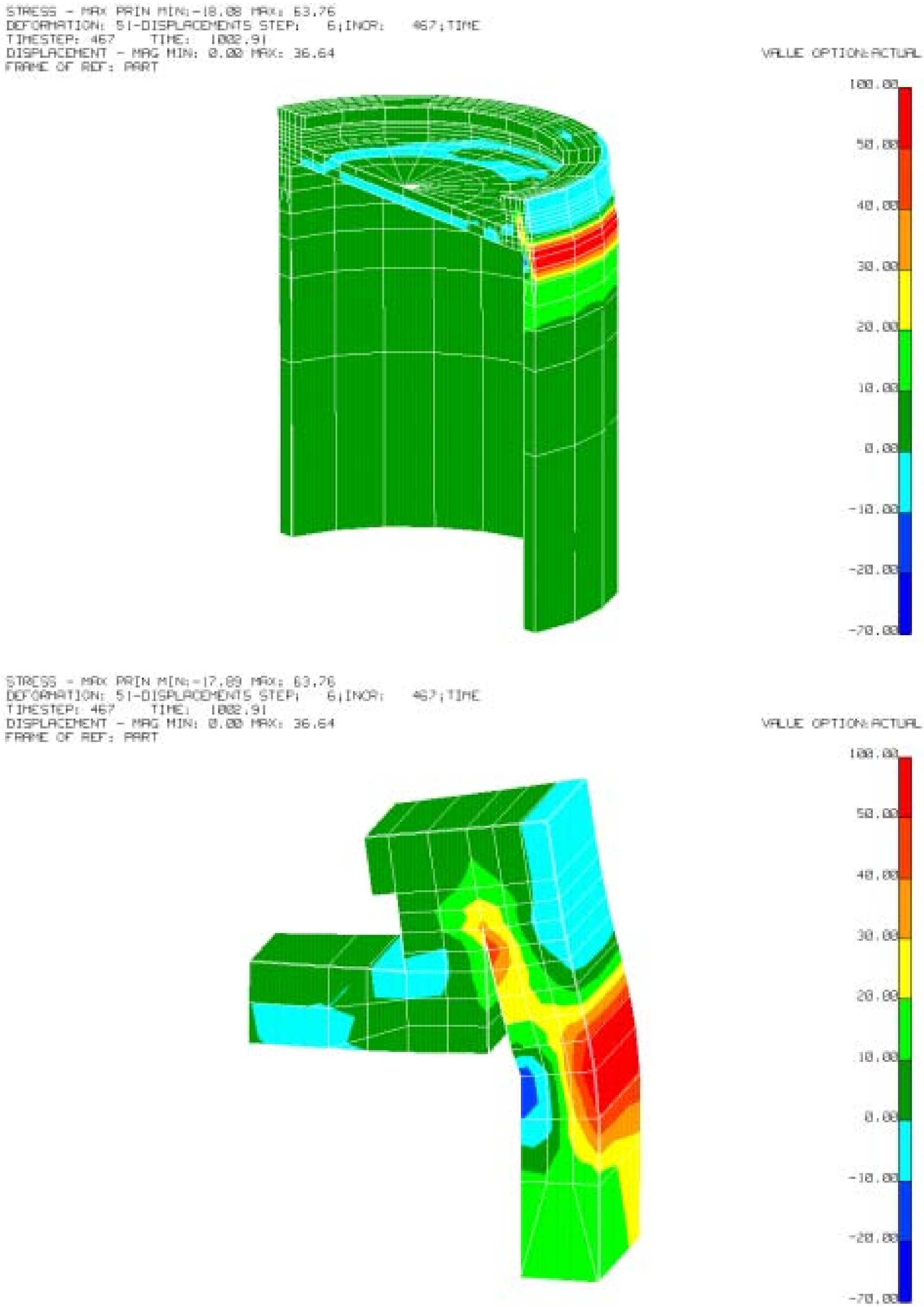


Figure 32 Max principal stress, MPa. Load case 4 creep 1000 years. Gap=1 mm between cylinder casing and insert.

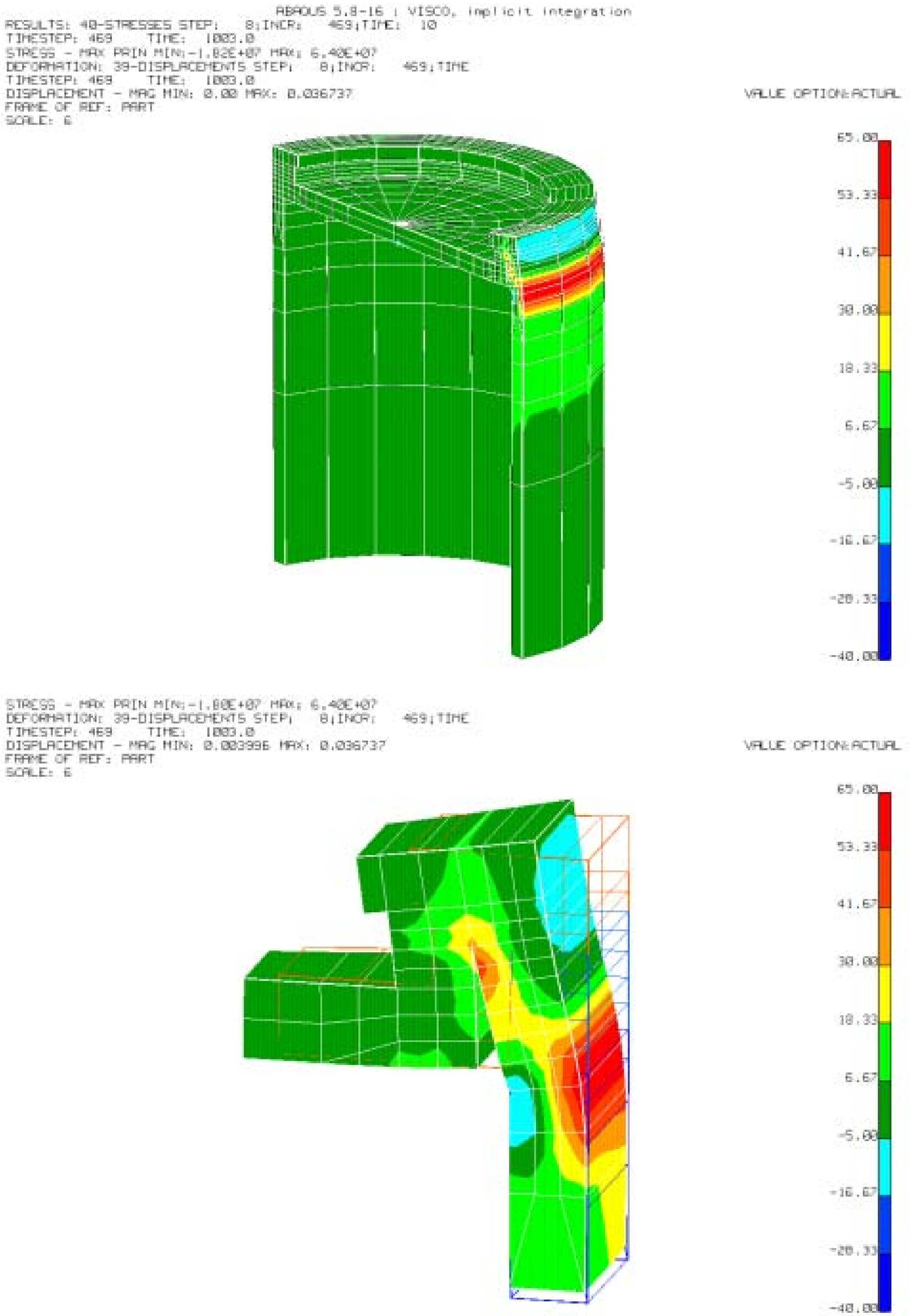


Figure 33 Max principal stress, MPa. Load case 4 creep 1000 years. Gap=2mm between cylinder casing and insert.

A.3.2 Creep strain

Load case 1 — Lid 15 MPa, cylinder 5 MPa

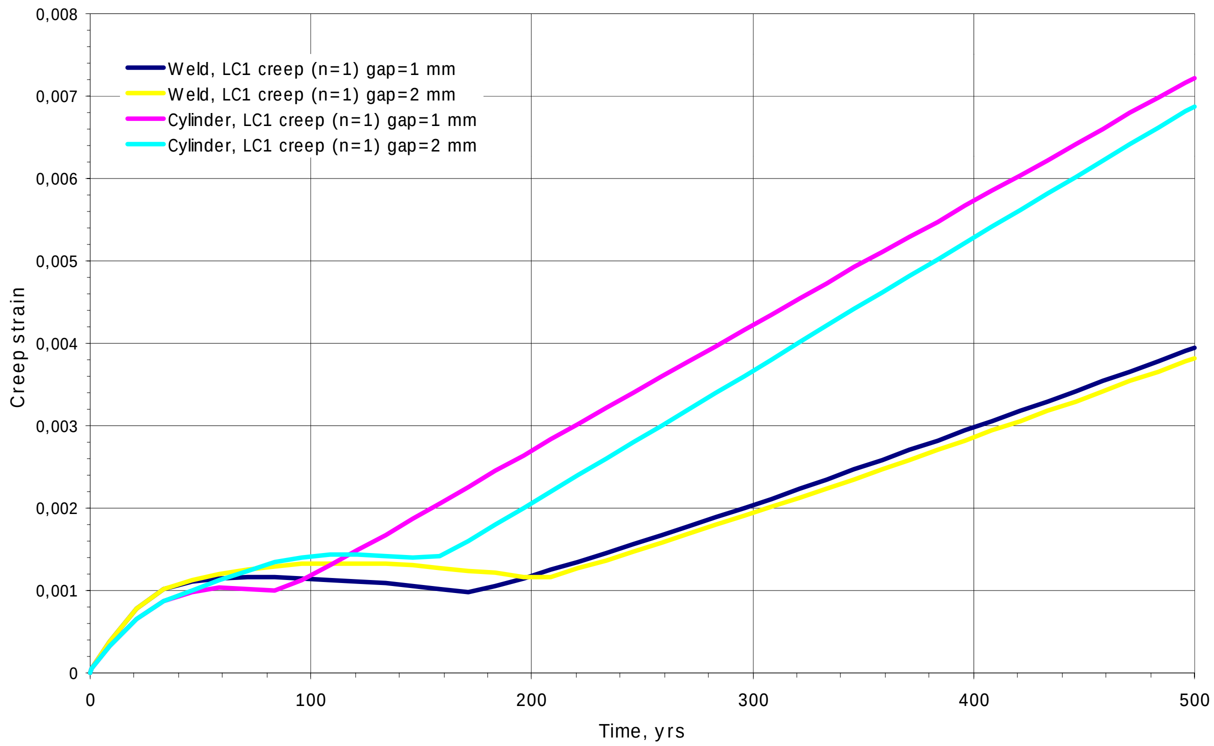


Figure 34 Max principal creep strain during creep 500 years. Load case 1. Comparison of creep strains in the weld and cylinder outside region for gap=1 mm and gap=2 mm between cylinder casing and insert.

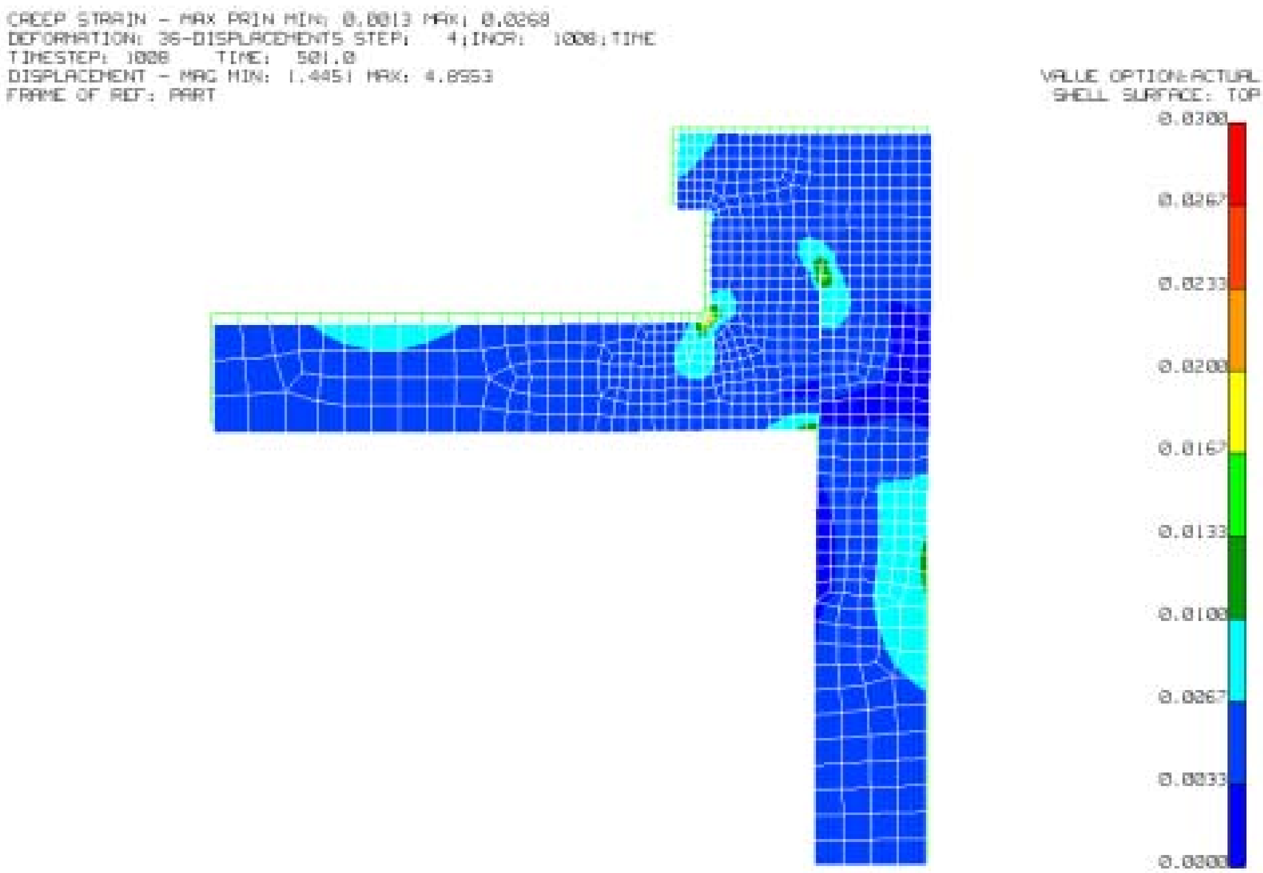


Figure 35 Max principal creep strain. Load case 1 creep 500 years. Gap=1 mm between cylinder casing and insert.

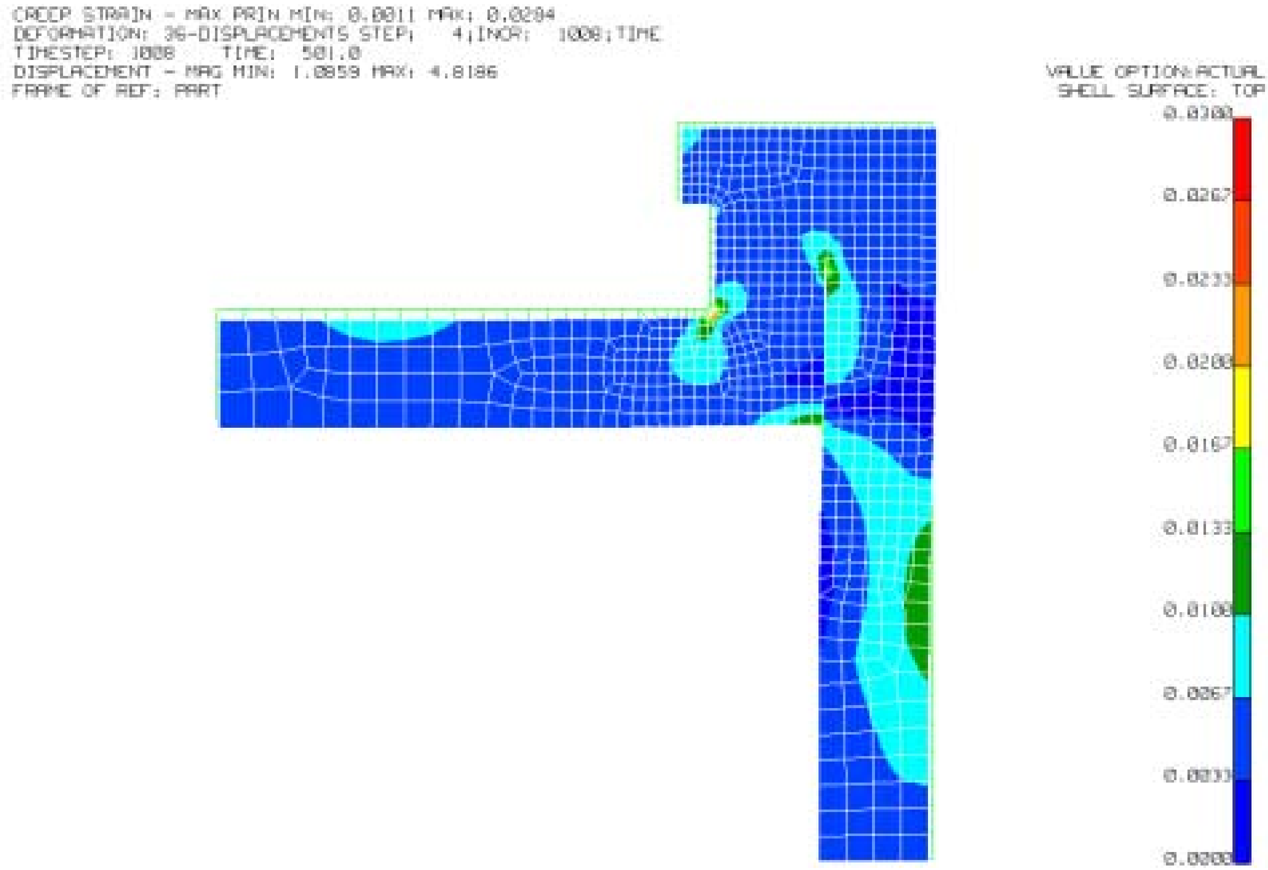


Figure 36 Max principal creep strain. Load case 1 creep 500 years. Gap=2mm between cylinder casing and insert.

Load case 4 — Side load 10 MPa

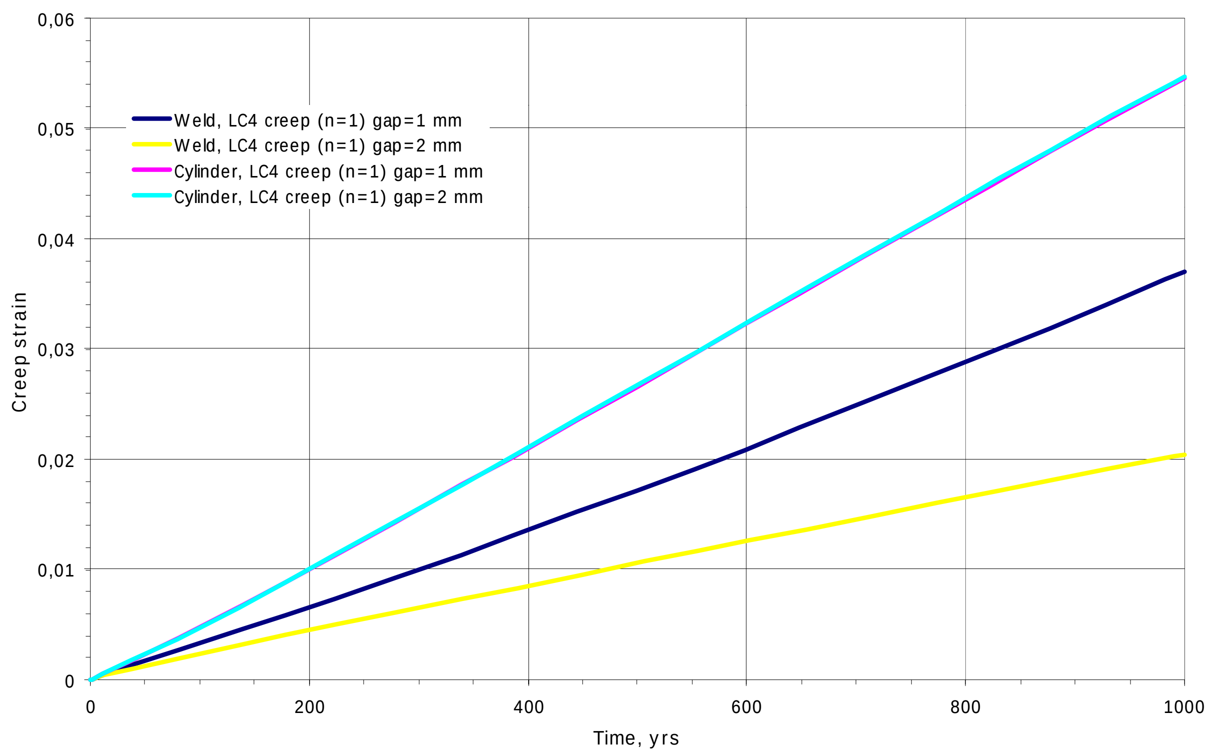
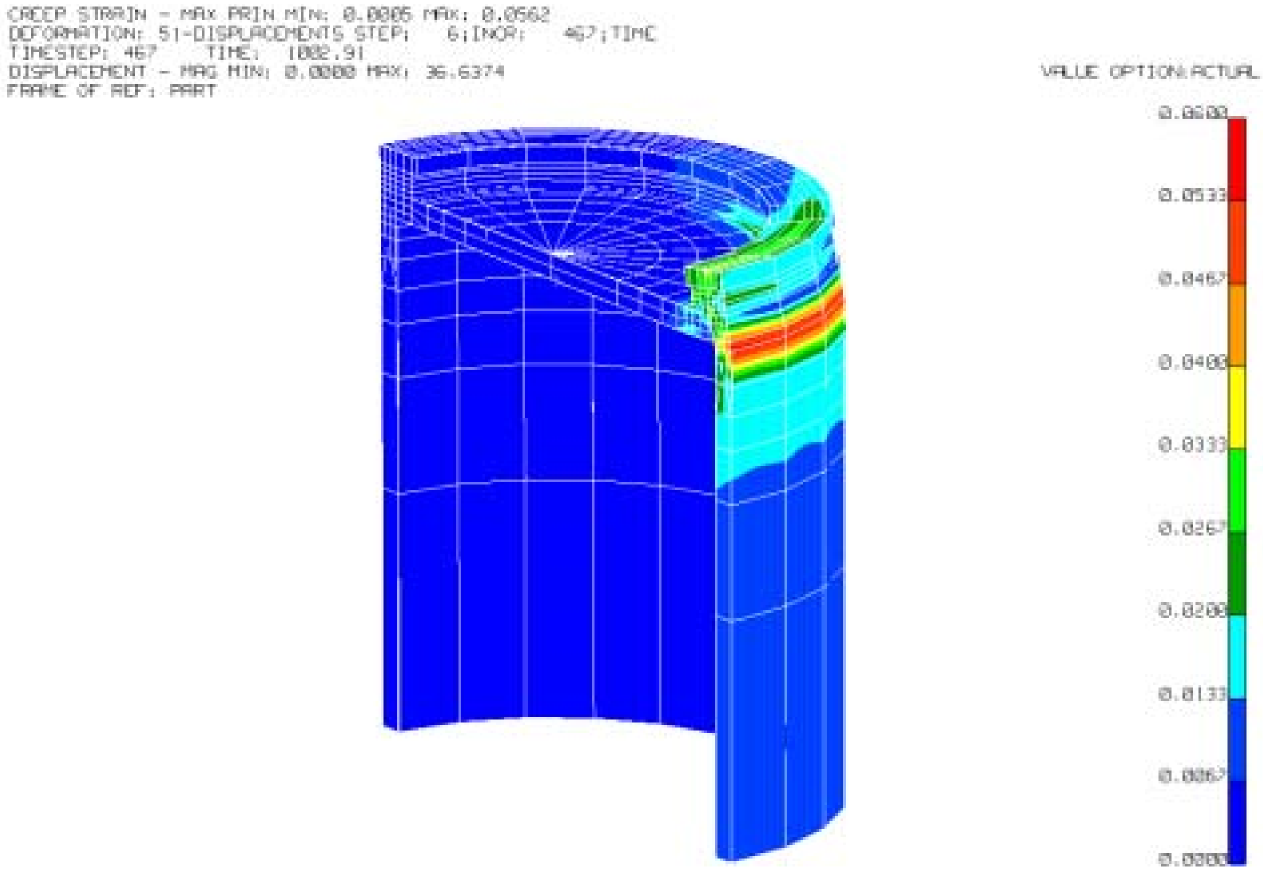


Figure 37 Max principal creep strain during creep 1000 years. Load case 4. Comparison of creep strains in the weld and cylinder outside region for gap=1 mm and gap=2 mm between cylinder casing and insert.



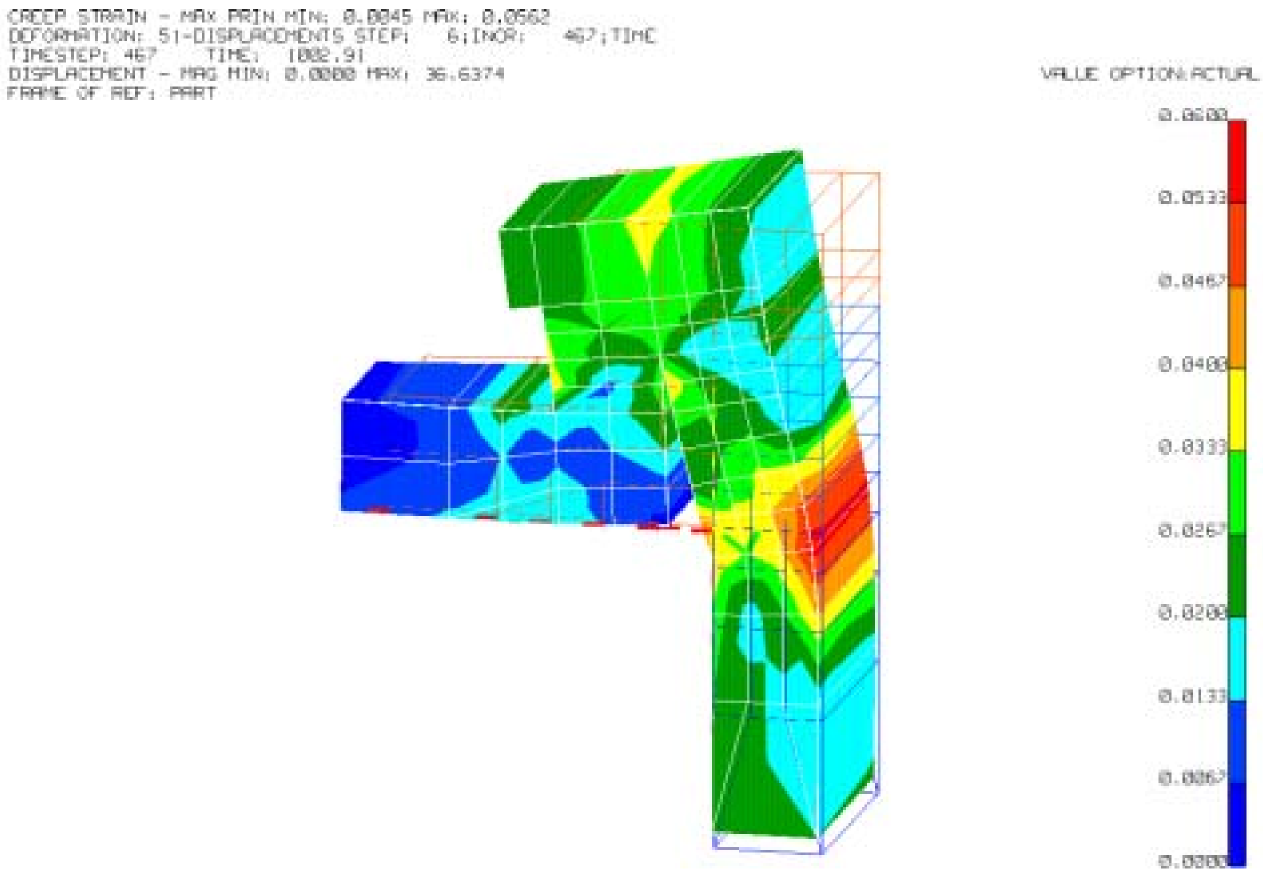


Figure 38 Max principal creep strain. Load case 4 creep 1000 years. Gap=1 mm between cylinder casing and insert.

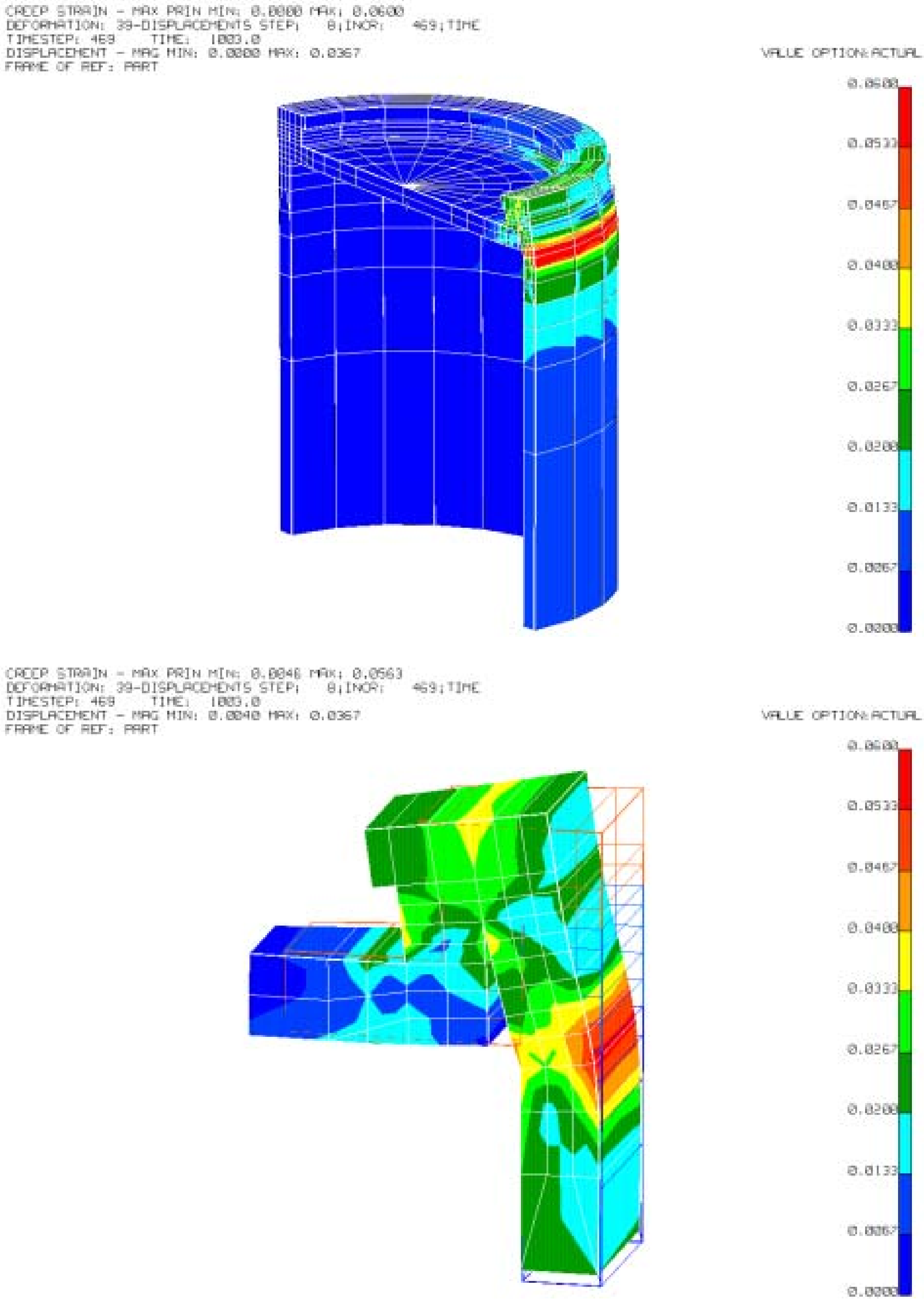


Figure 39 Max principal creep strain. Load case 4 creep 1000 years. Gap=2mm between cylinder casing and insert.

B Creep study

The creep study is performed for one design, for the design where the gap between cylinder casing and the cast iron inserts is 1 mm. Two creep equations are used in the calculations to evaluate how the creep modelling affect the resulting stresses and strains. Results presented are maximum principal stresses and creep strains.

B.1 Contact

The graphs in *Figure 40* and *Figure 41* show how the gap between cylinder casing and lid, and between cylinder casing and insert varies during creep when using two different creep equations. Results are extracted from the contact elements denoted in *Figure 5* and *Figure 6*.

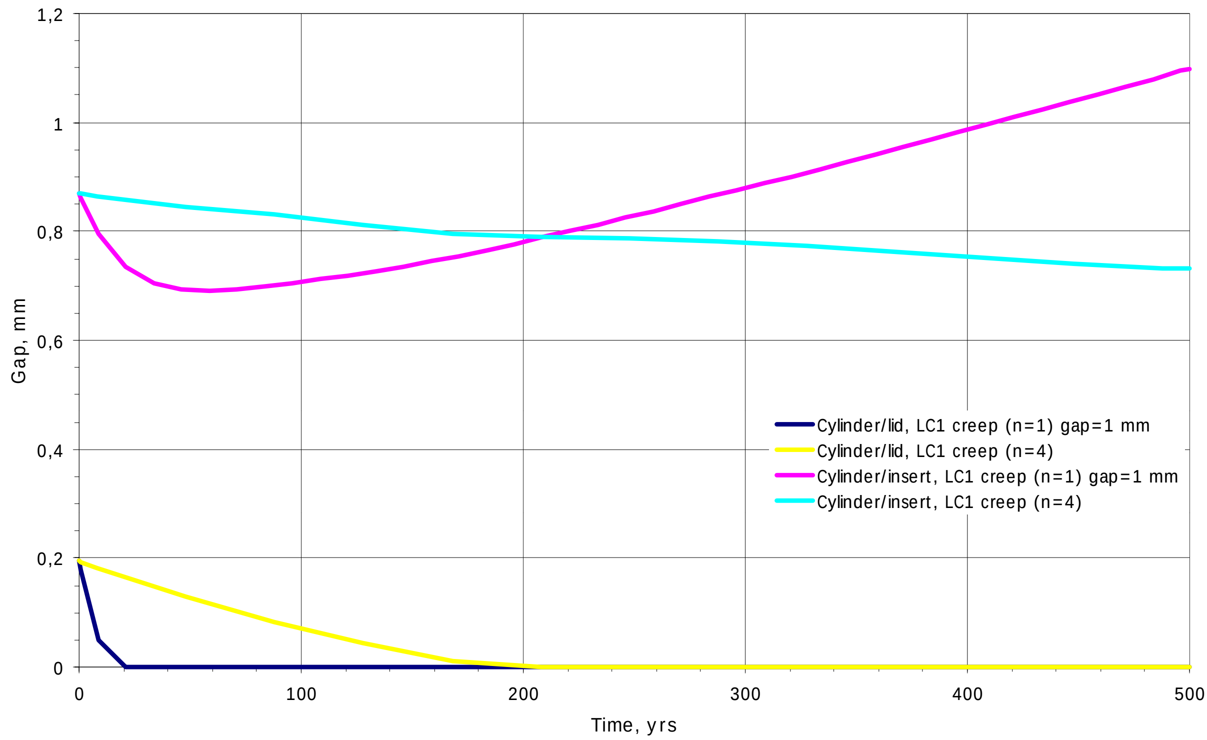


Figure 40 Gap distance, mm. Load case 1 creep 500 years. Comparison of gap distance during creep using creep equation 1 (n=1) and creep equation 2 (n=4), respectively.

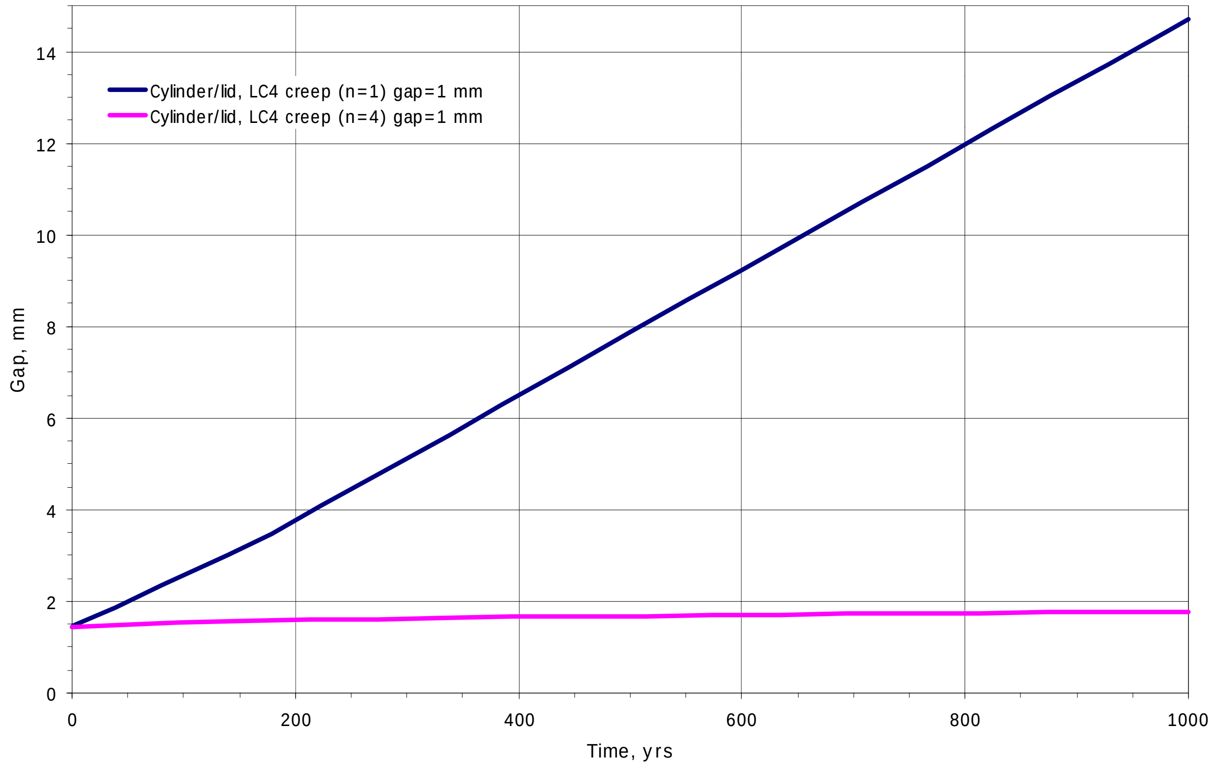


Figure 41 Gap distance, mm. Load case 4 creep 1000 years. Comparison of gap distance during creep using creep equation 1 (n=1) and creep equation 2 (n=4), respectively.

B.2 Stress

Load case 1 — Lid 15 MPa, cylinder 5 MPa

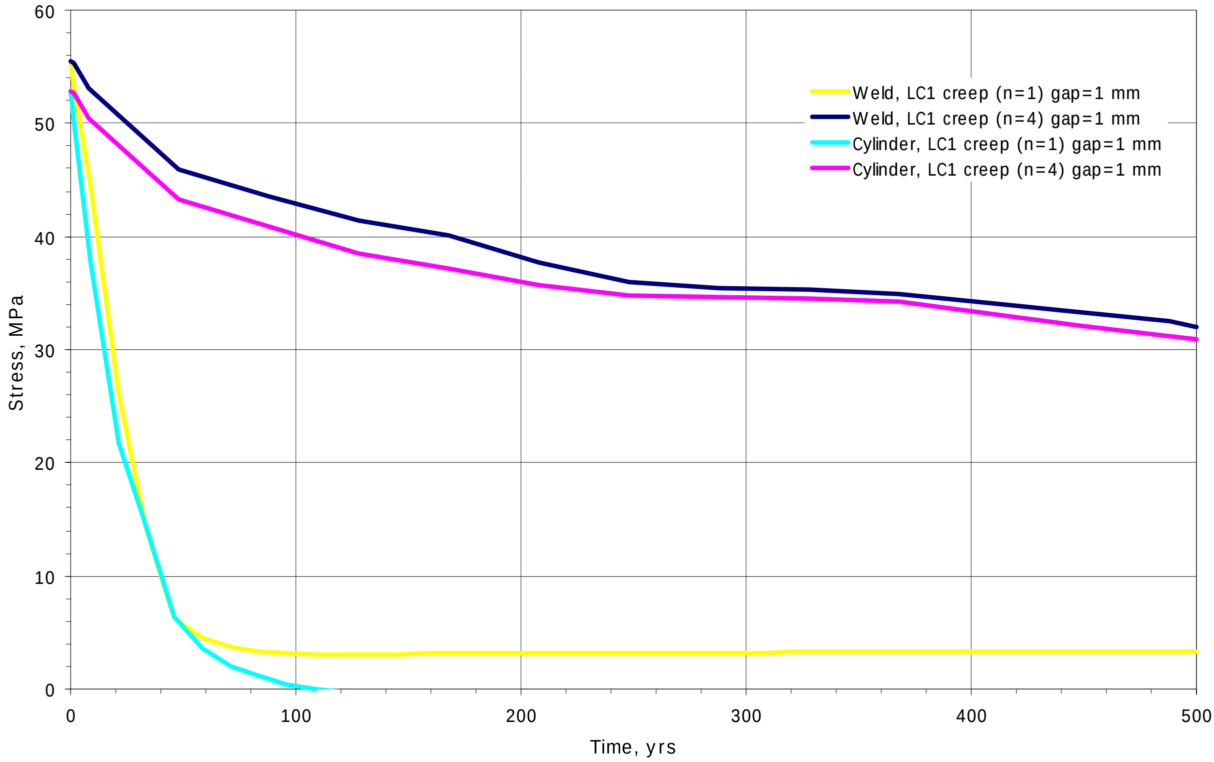


Figure 42 Max principal stress during creep 500 years (MPa). Load case 1. Comparison of creep strains in the weld and cylinder outside region when using creep equation 1 (n=1) and 2 (n=4), respectively.

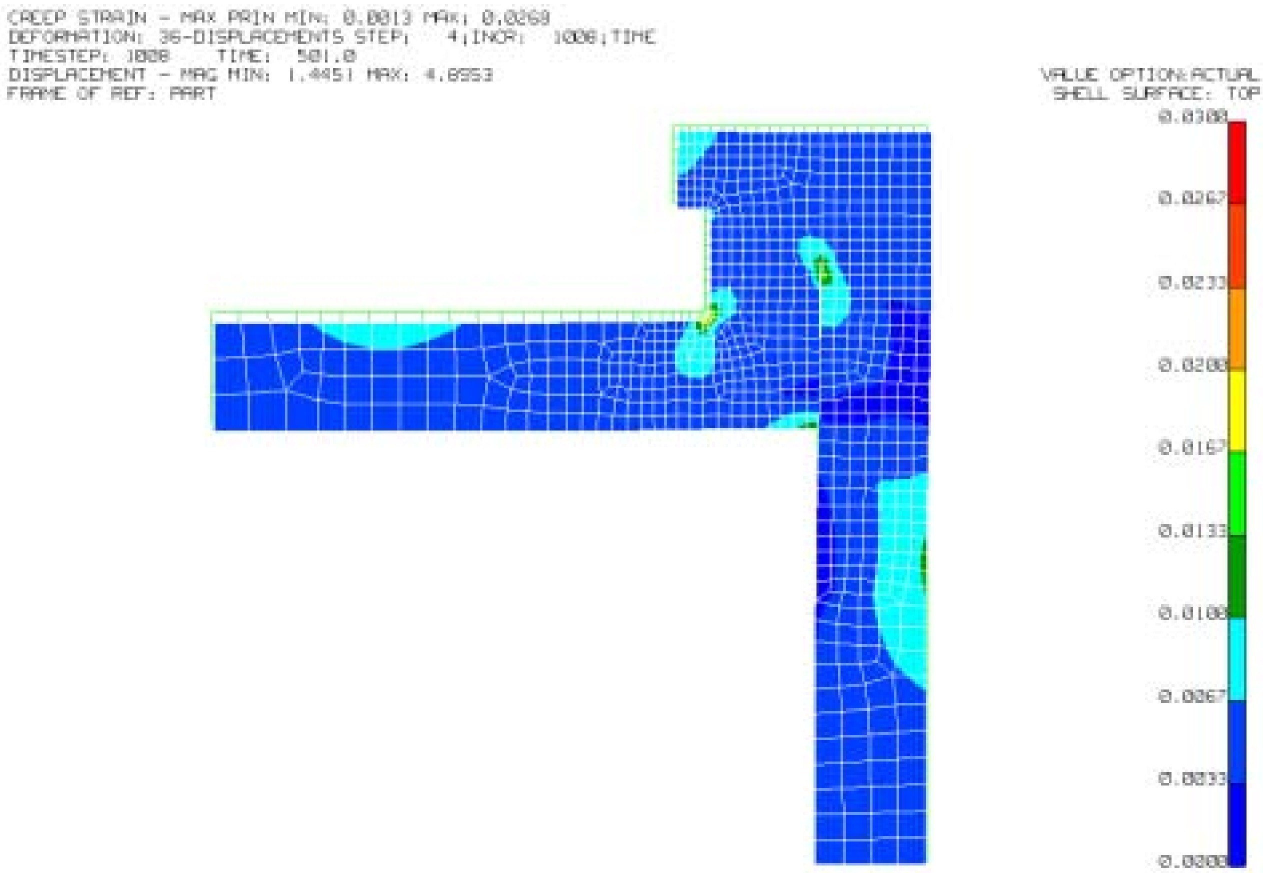


Figure 43 Max principal stress, MPa. Load case 1 creep 500 years. Creep equation 1, where n=1.

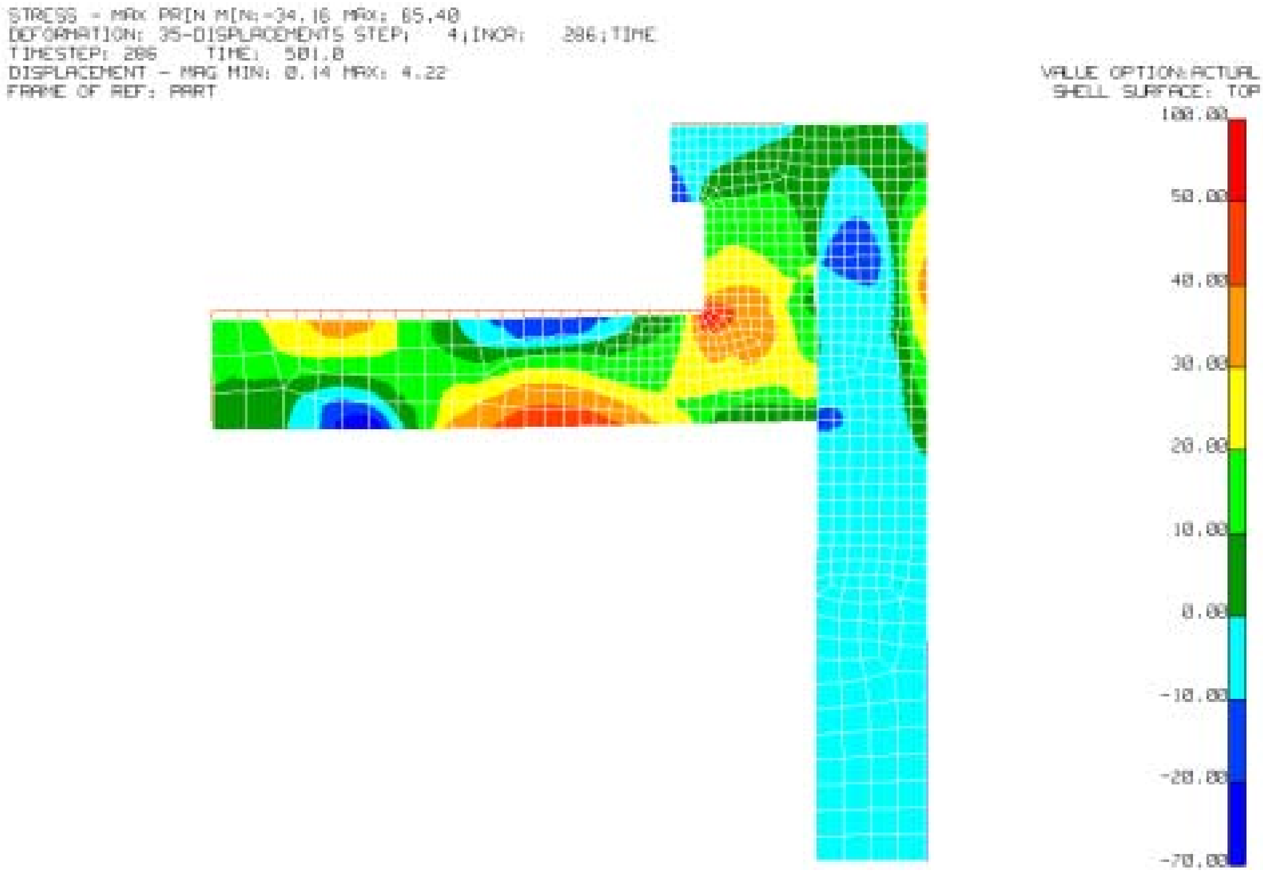


Figure 44 Max principal stress, MPa. Load case 1 creep 500 years. Creep equation 2, where n=4.

Load case 4 — Side load 10 MPa

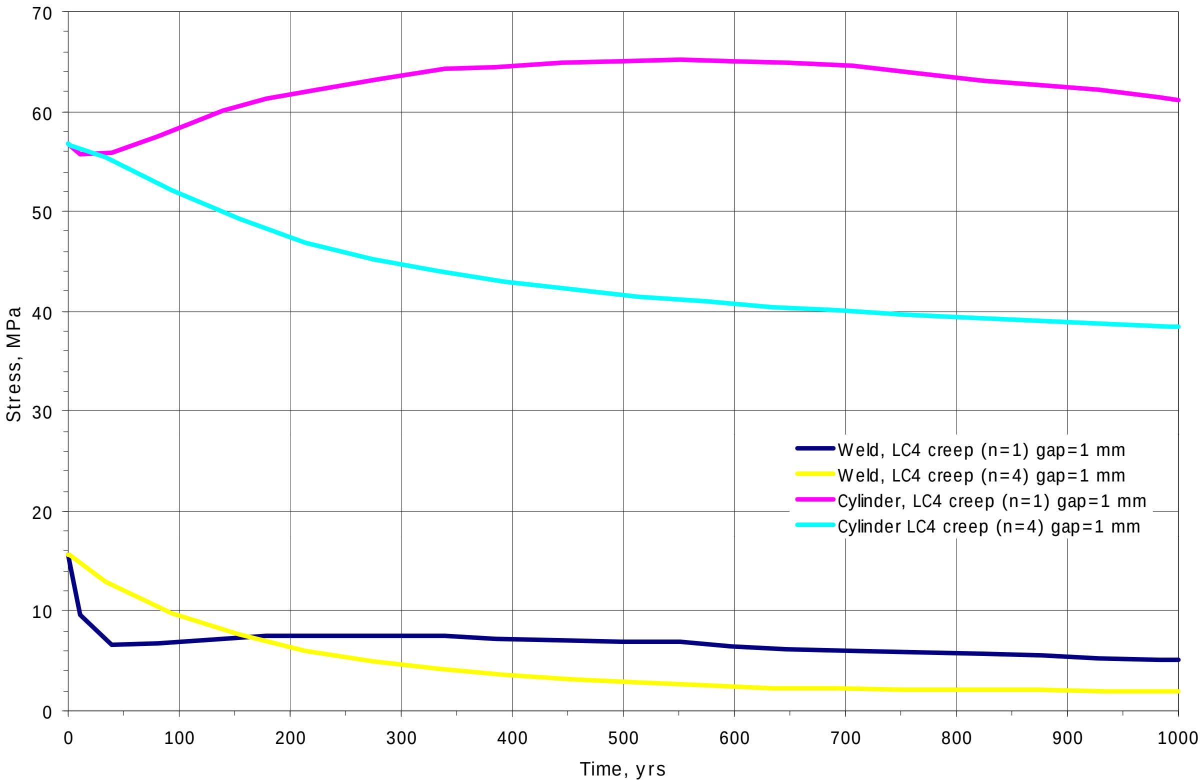
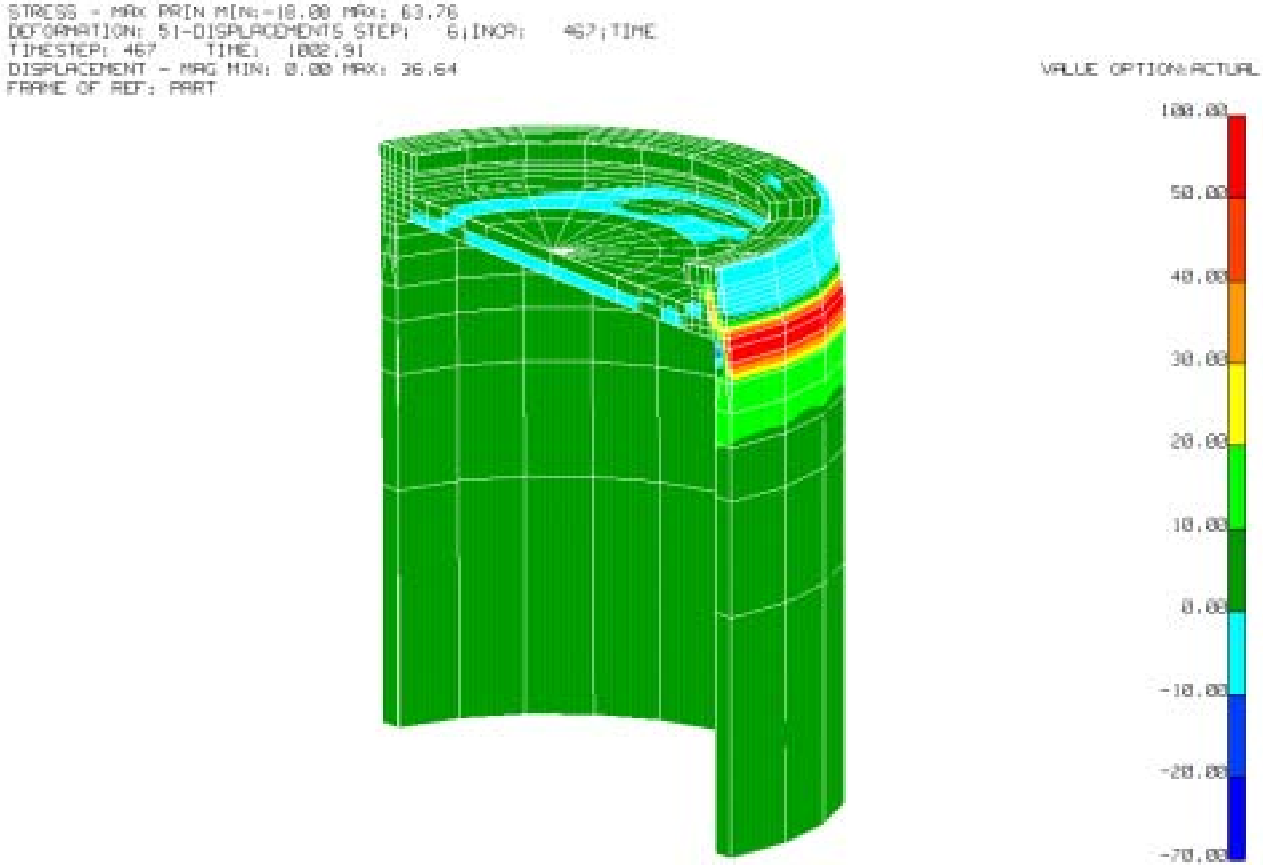


Figure 45 Max principal stress during creep 1000 years (MPa). Load case 4. Comparison of creep strains in the weld and cylinder outside region when using creep equation 1 (n=1) and 2 (n=4), respectively.



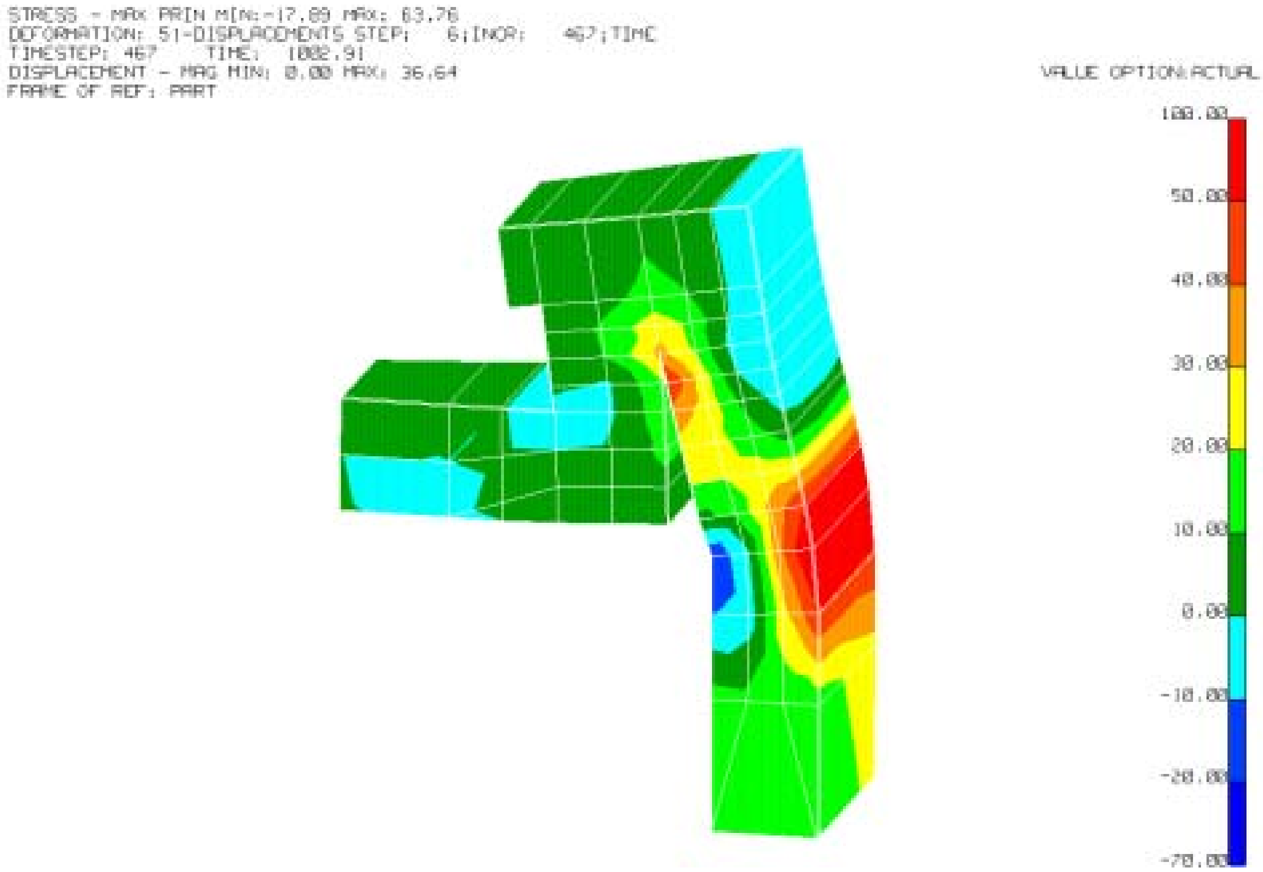


Figure 46 Max principal stress, MPa. Load case 4 creep 1000 years. Creep equation 1, where n=1.

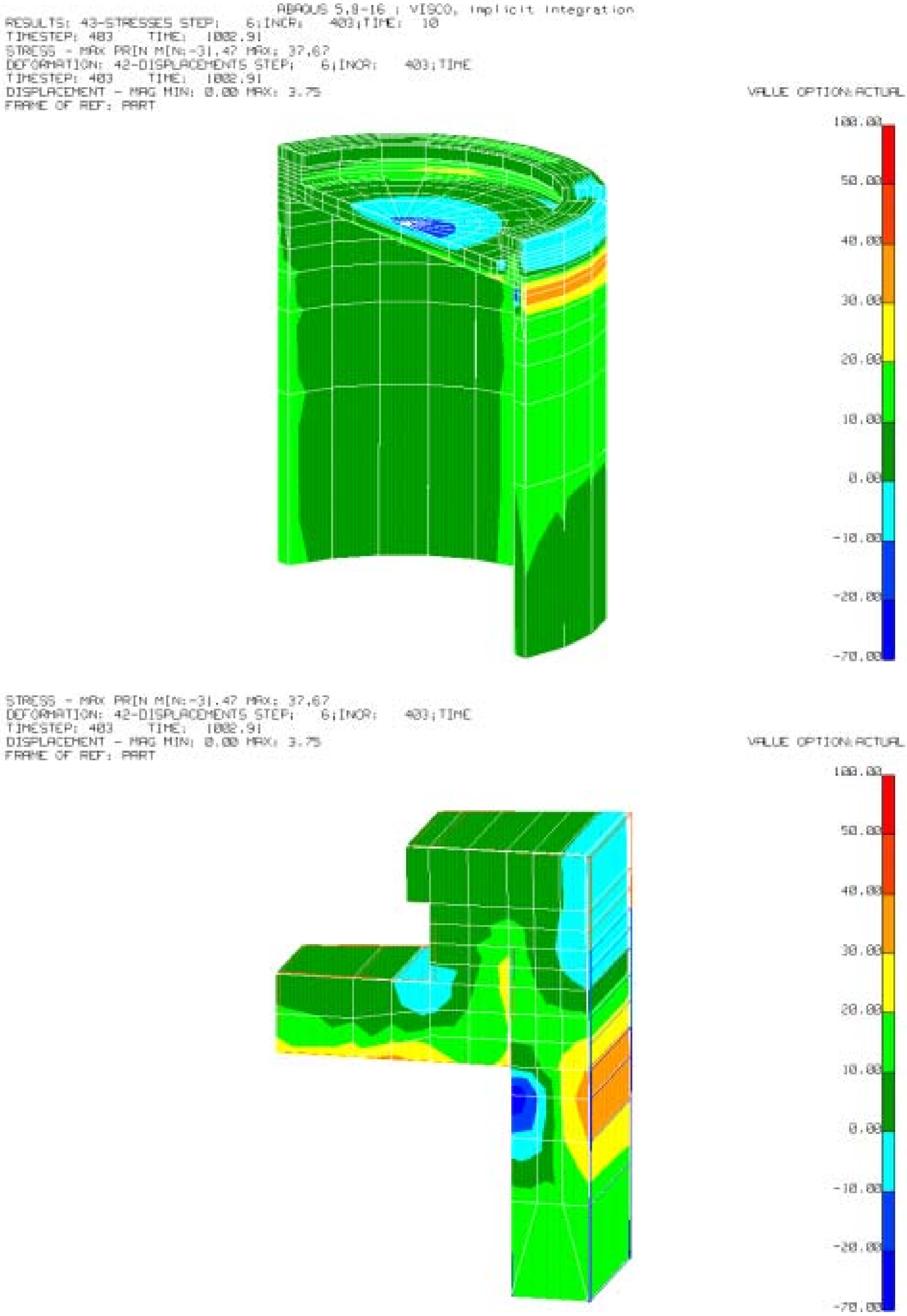


Figure 47 Max principal stress, MPa. Load case 4 creep 1000 years. Creep equation 1, where n=1.

B.3 Creep strain

Load case 1 — Lid 15 MPa, cylinder 5 MPa

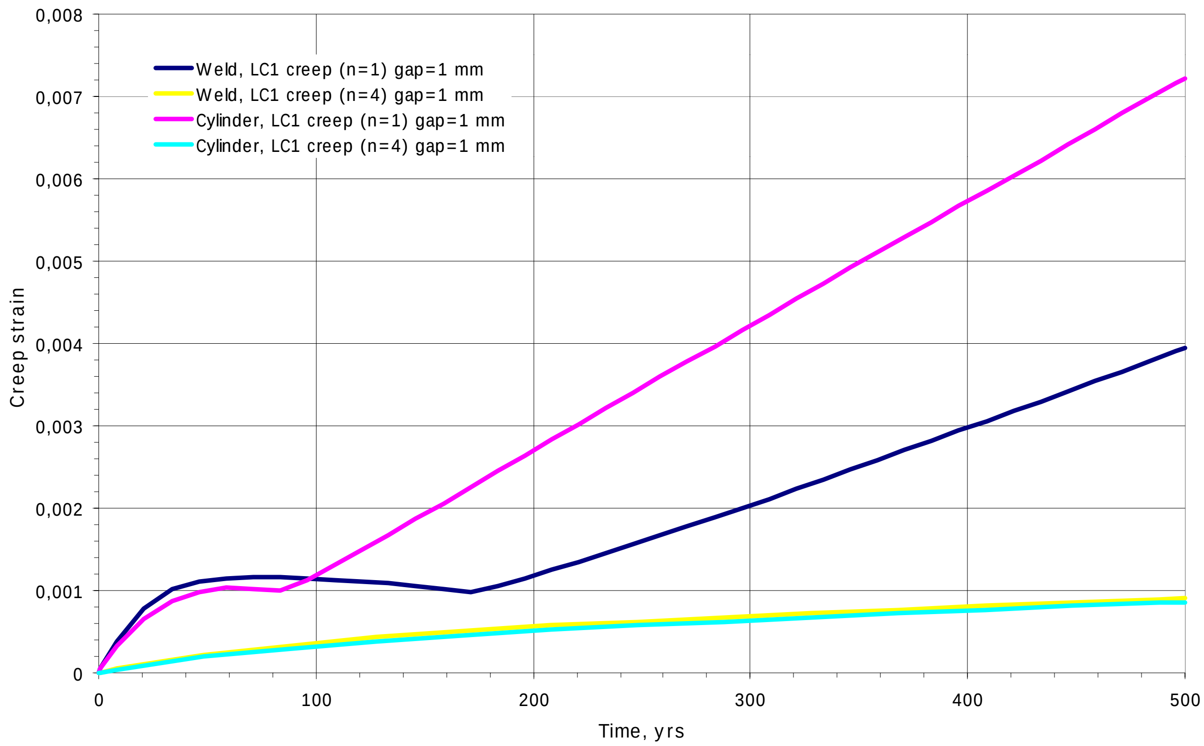


Figure 48 Max principal creep strain during creep 500 years. Load case 1. Comparison of creep strains in the weld and cylinder outside region when using creep equation 1 (n=1) and 2 (n=4), respectively.

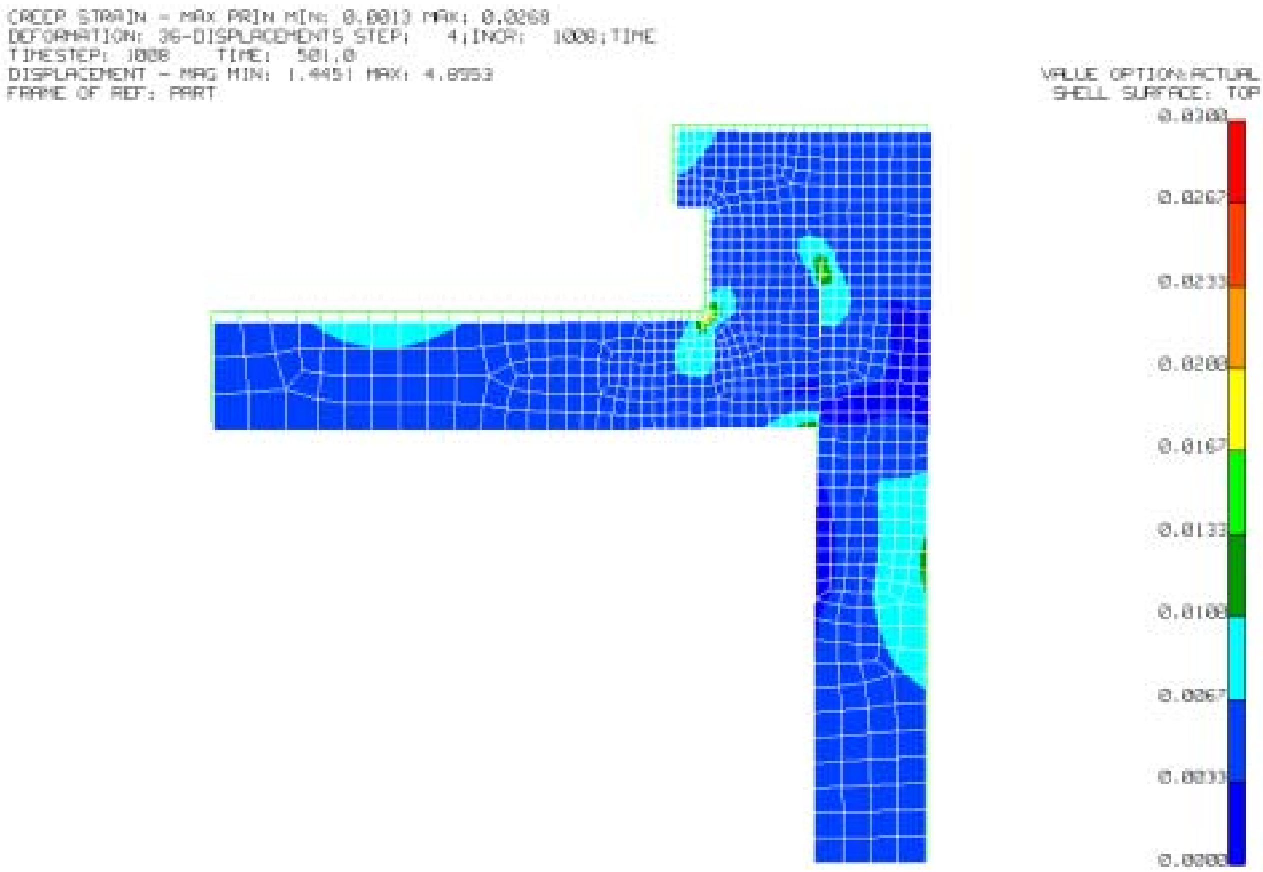


Figure 49 Max principal creep strain. Load case 1 creep 500 years. Creep equation 1, where n=1.

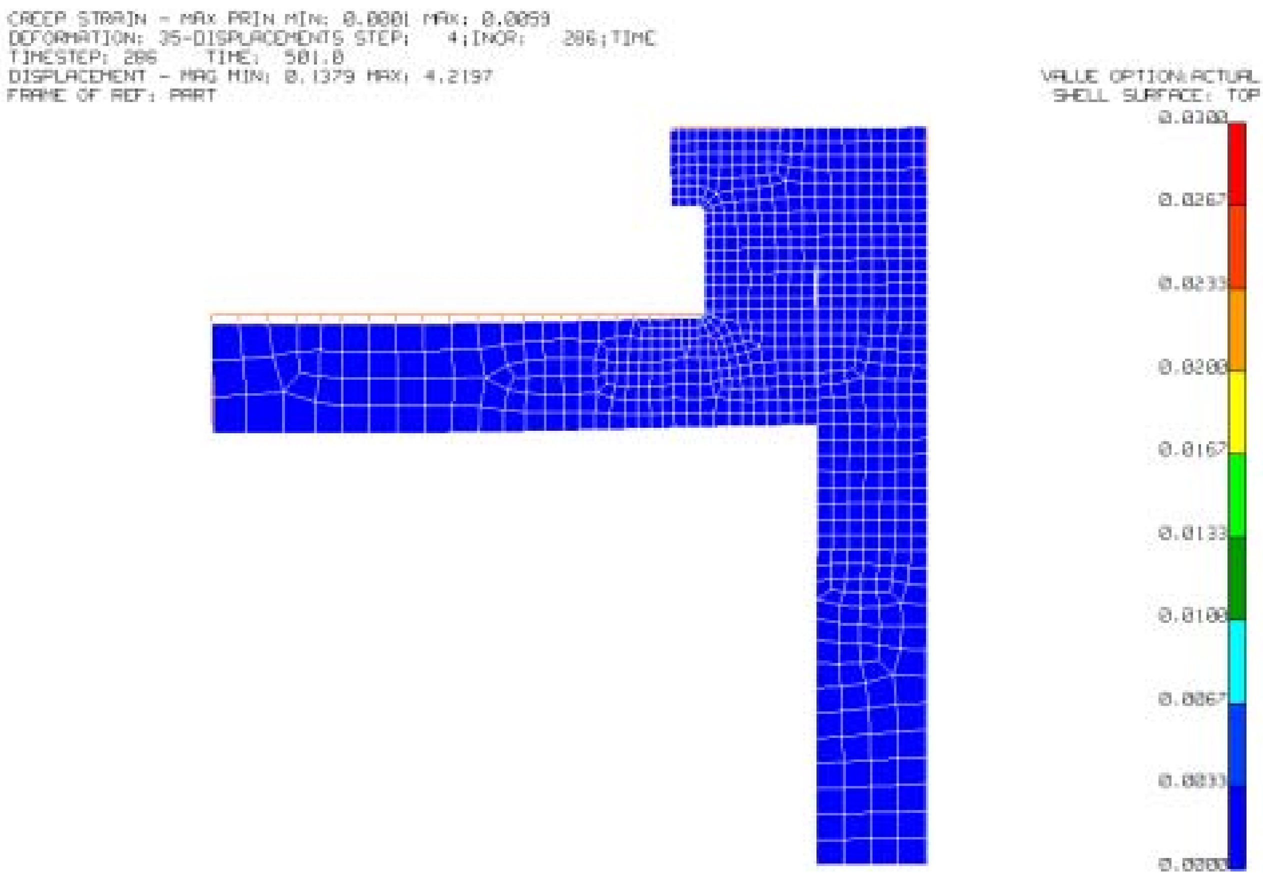


Figure 50 Max principal creep strain. Load case 1 creep 500 years. Creep equation 2, where n=4.

Load case 4 — Side load 10 MPa

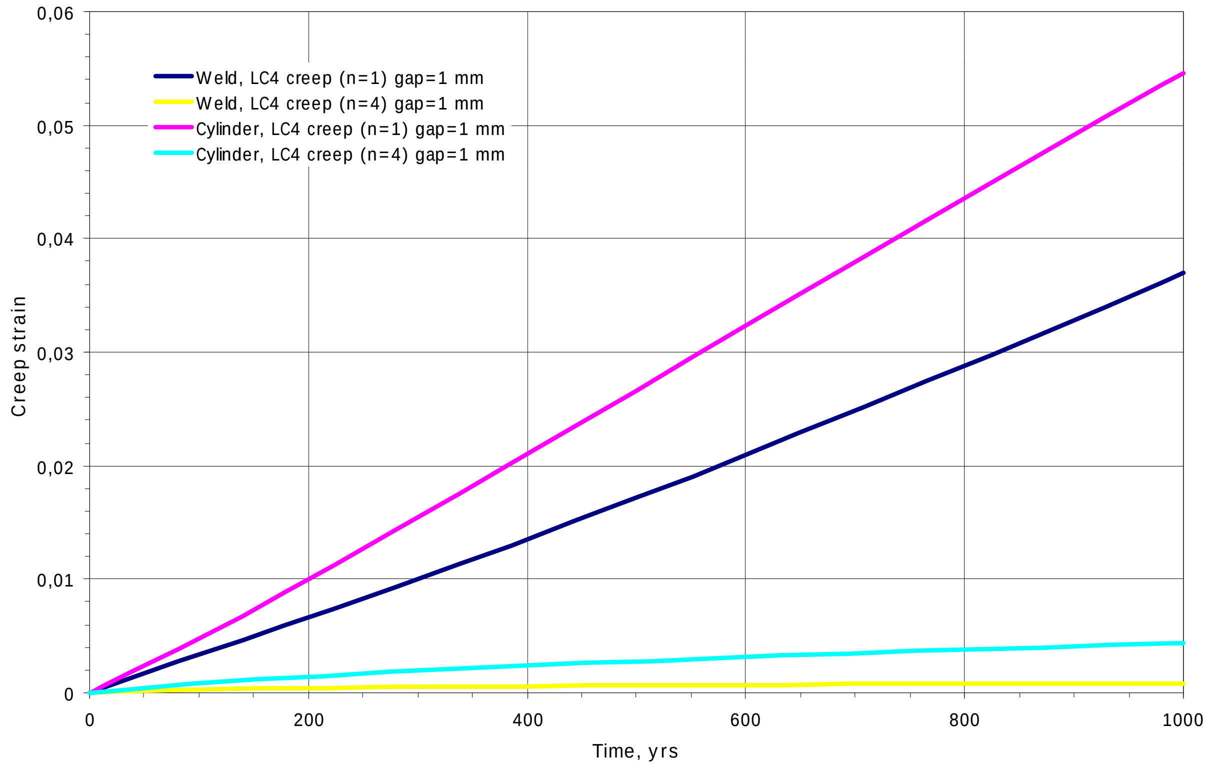


Figure 51 Max principal creep strain during creep 1000 years. Load case 4. Comparison of creep strains in the weld and cylinder outside region when using creep equation 1 (n=1) and 2 (n=4), respectively

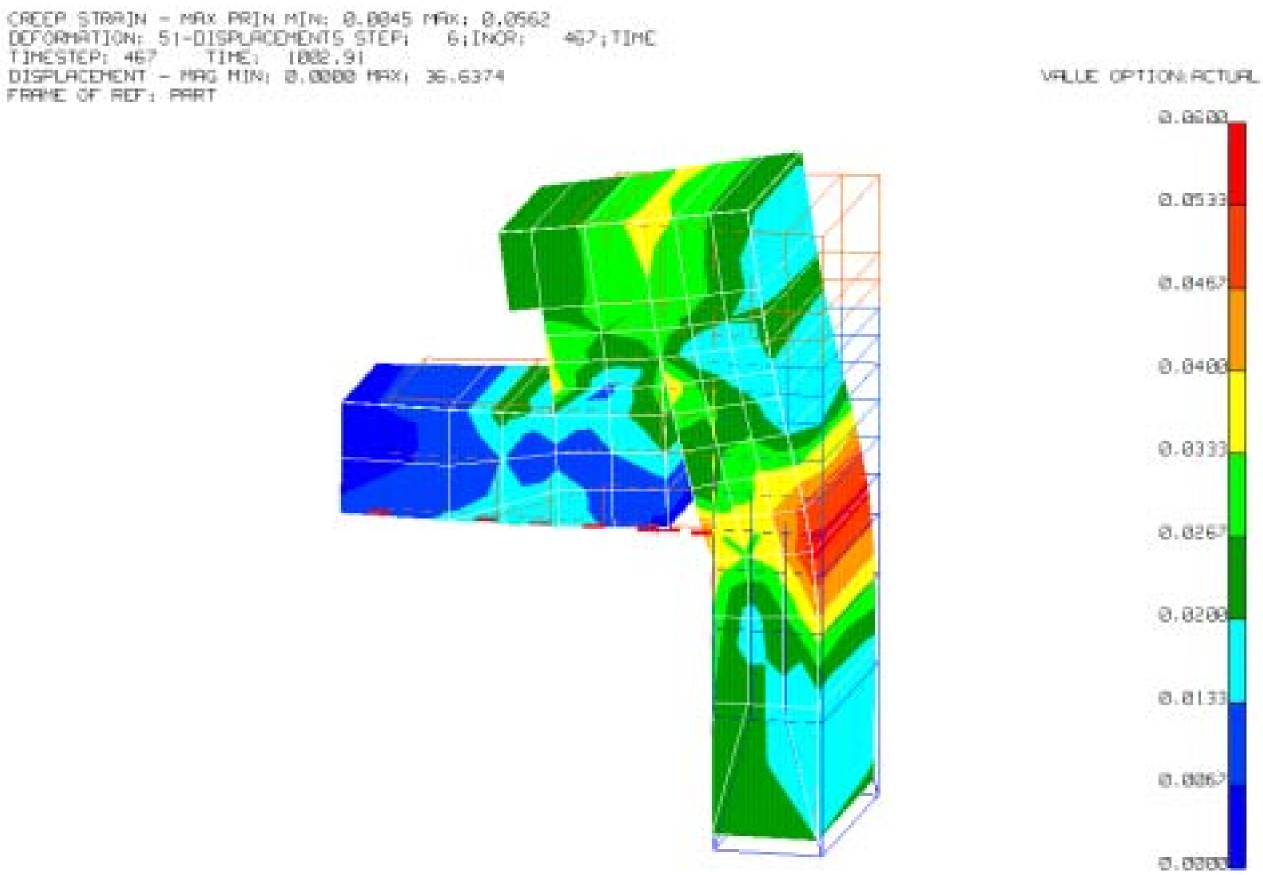


Figure 52 Max principal creep strain. Load case 4 creep 1000 years. Creep equation 1, where n=1.

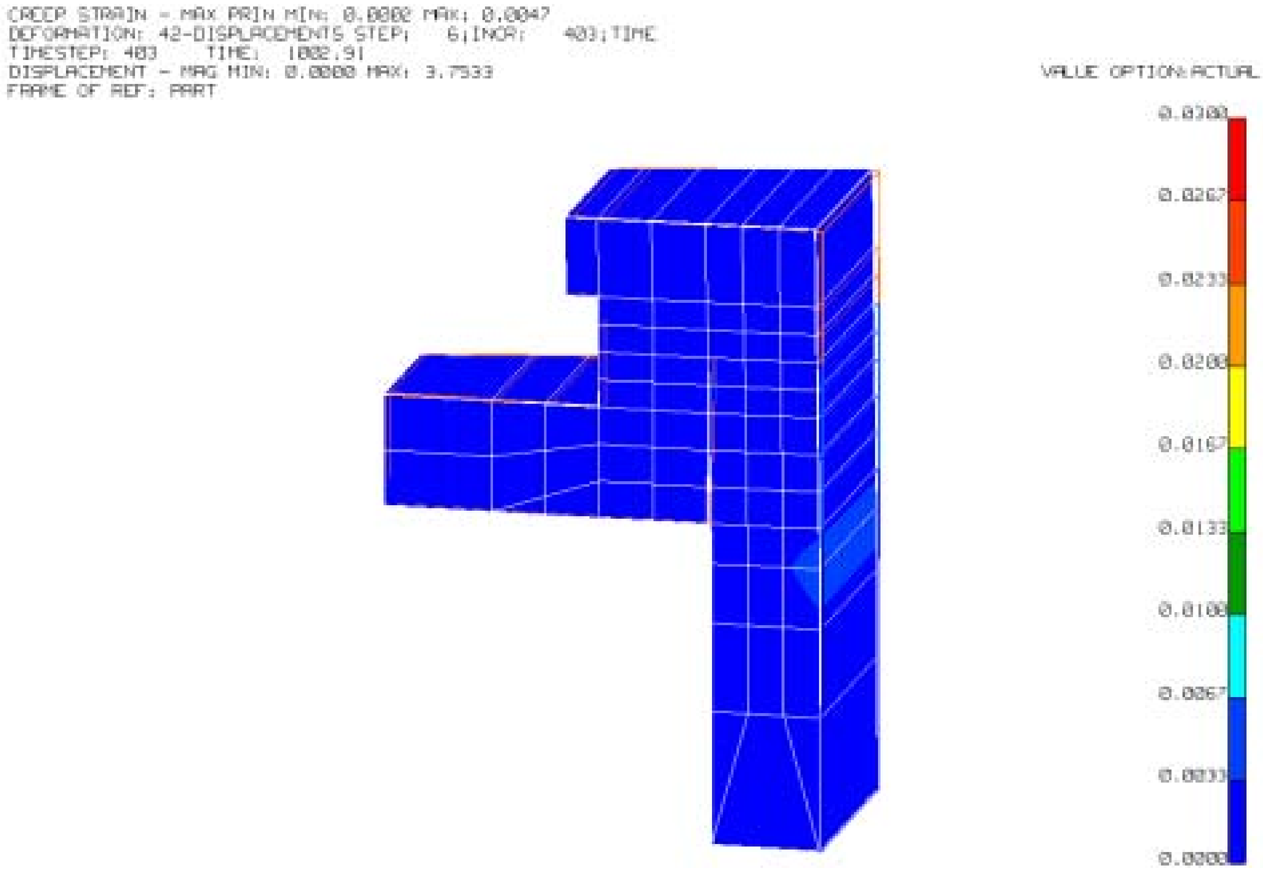


Figure 53 Max principal creep strain. Load case 4 creep 1000 years. Creep equation 2, where n=4.