Report Prepared for

GFR

Vent Master PX Finite Element Analysis

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Document Control

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A	24/07/2013	Preliminary issue.	MR	JdV
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2	16/08/2013	Corrected load case description	FD	MR

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1. EXECUTIVE SUMMARY

This report presents the results of the finite element analysis (FEA) of a pipeline vent valve. The following is the summary of the analysis procedures and results:

1. The following standards were adopted for the load scenarios:
   a. AS 2566.1:1998 *Buried flexible pipelines Part 1: Structural design;*
   b. AS 4130:2009 *Polyethylene (PE) pipes for pressure applications;*
   c. AS 1210-2010: *Pressure Vessels*
2. Two load scenarios were modelled:
   a. Long term (50 years) internal pressure of 1600 kPa at 20ºC
   b. Pressure surge raising internal pressure to 2000 kPa at 20ºC
3. The valve was modelled using Strand7, release 2.4.5, FEA software;
4. The geometry of the valve was based on the following drawings supplied by GFR:
   a. GFR-PXD-000 Rev 3
5. The allowable stress calculated according to AS1210-2010 was 27 MPa;
6. The stresses in the valve did not exceed allowable limits;
7. The valve material has a service life limited to 50 years

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2. INTRODUCTION

GFR engaged Deacon Engineers to carry out FEA of the Vent Master PX valve in order to assess the strength of the body of the valve. The valve is designed to vent gases and prevent vacuum collapse in pipelines.

3. ANALYSIS INPUTS

3.1 Design standards

The following standards were adopted for the analysis:

- AS 2566.1-1998: *Buried flexible pipelines Part 1: Structural design*;
- AS 4130-2009: *Polyethylene (PE) pipes for pressure applications*;
- AS 1210-2010: *Pressure Vessels*;

3.2 Geometry

The geometry of the valve was based on the following drawings supplied by GFR:

- GFR-PXD-000 Rev 3

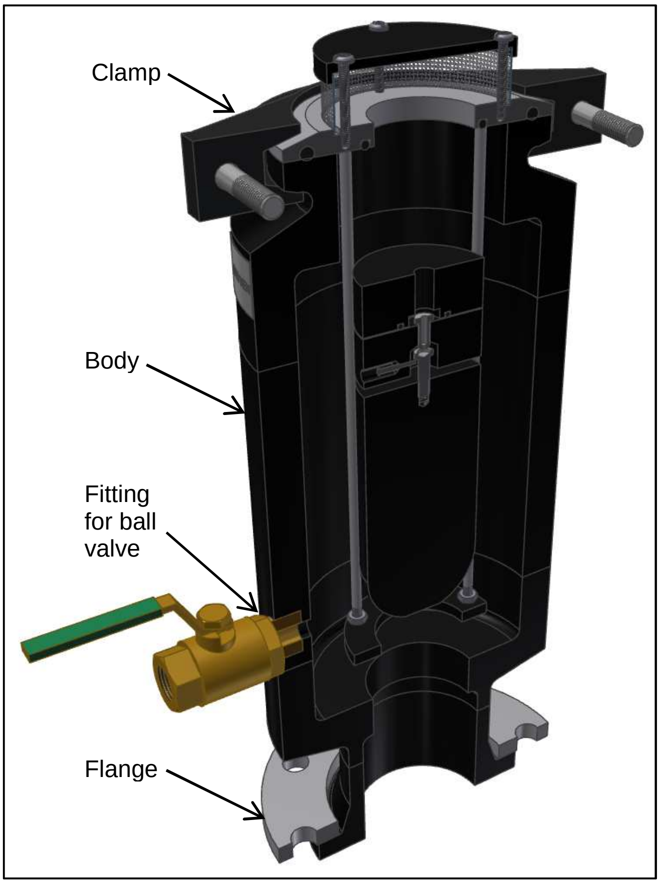


Figure 1 – Cut-away model of the Vent Master PX valve.

3.3 FEA model

Strand7 release 2.4.5 was used to carry out the FEA of the valve. The valve was modelled using predominantly Hexa8 elements, but also contained Tetra4 and Wedge6 elements in limited areas. Only the body, clamp and flange were modelled. Half of the body and flange were modelled due to symmetry of the geometry and boundary conditions. One-quarter of the clamp was modelled due to symmetry of the geometry and boundary conditions. The model was restrained along the symmetry planes, and the pressure load normally acting upwards on the top covering components of the valve was transferred to the flange, acting downwards. Non-linear contact was modelled between the clamp and body and body and flange. The bolts joining the two halves of the clamp were modelled using a combination of master-slave and pinned links.

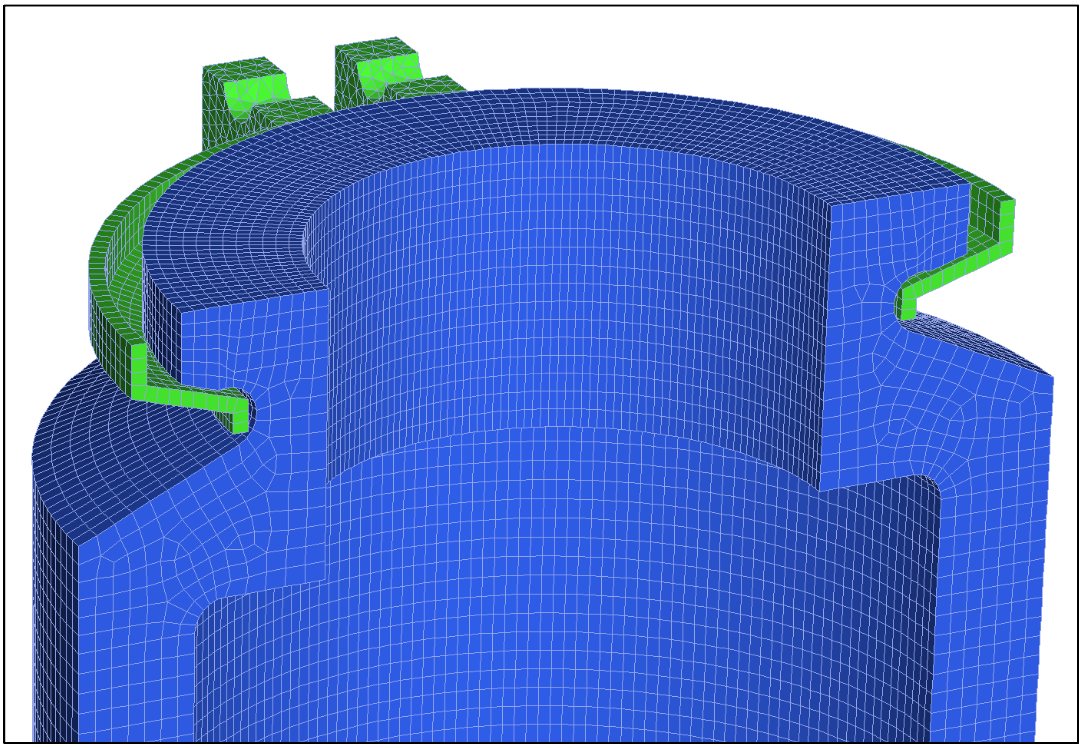


Figure 2 – FEA mesh of quarter-clamp and half-valve-body geometry.

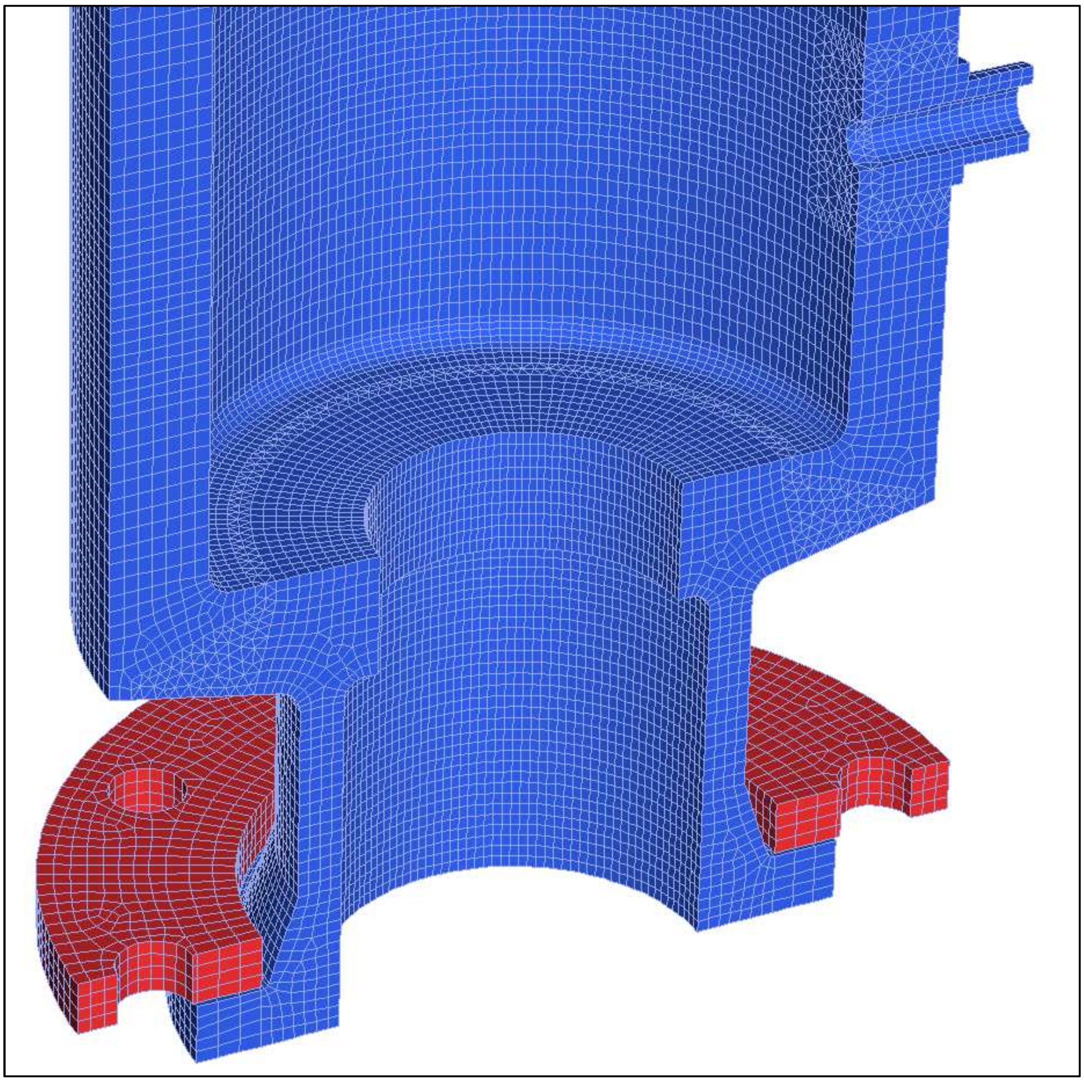


Figure 3 – FEA mesh of half-flange and half-valve-body geometry.

3.4 Applied loads

A unit internal pressure of 1000 kPa was applied to the internal surfaces of the valve body. A unit pressure of 549 kPa was applied to the face of the fitting to model a closed ball valve. A unit pressure of 378 kPa was applied in a downward direction on the upper face of the flange to model the reaction force generated by the pressure load normally acting upwards on the top covering components of the valve. These loads were subsequently scaled to model the various internal pressure load cases.

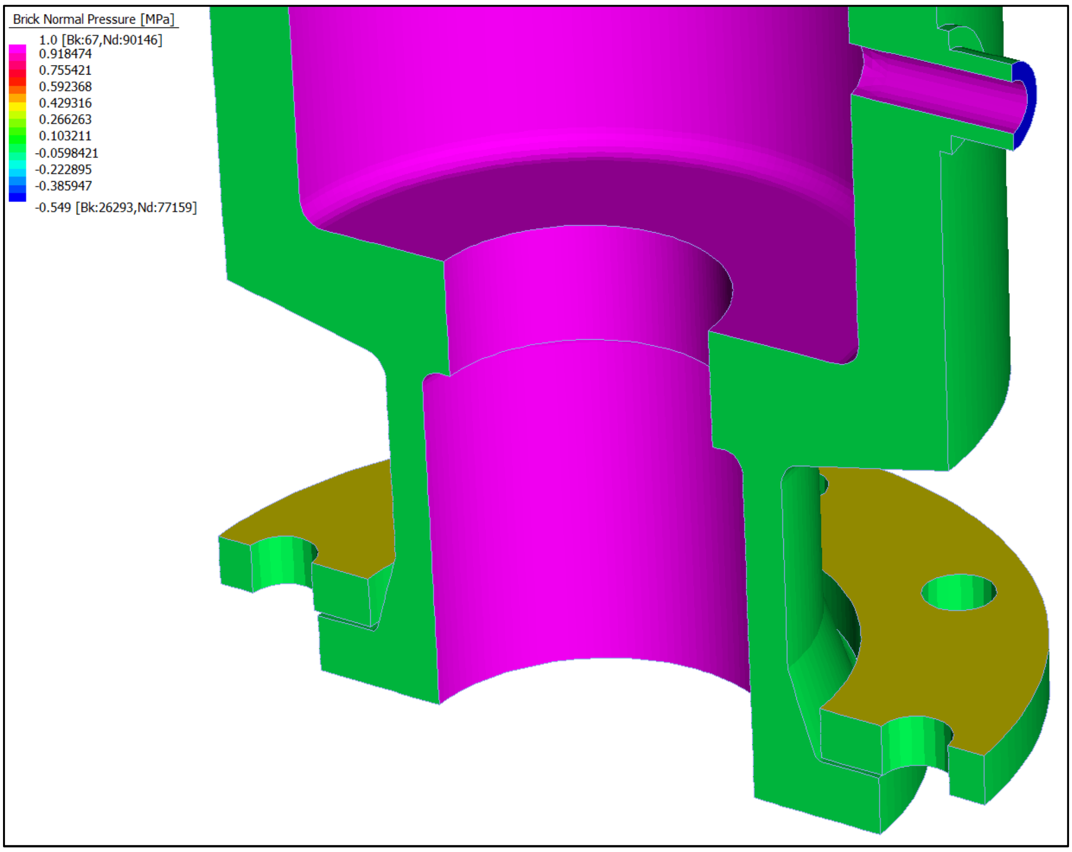


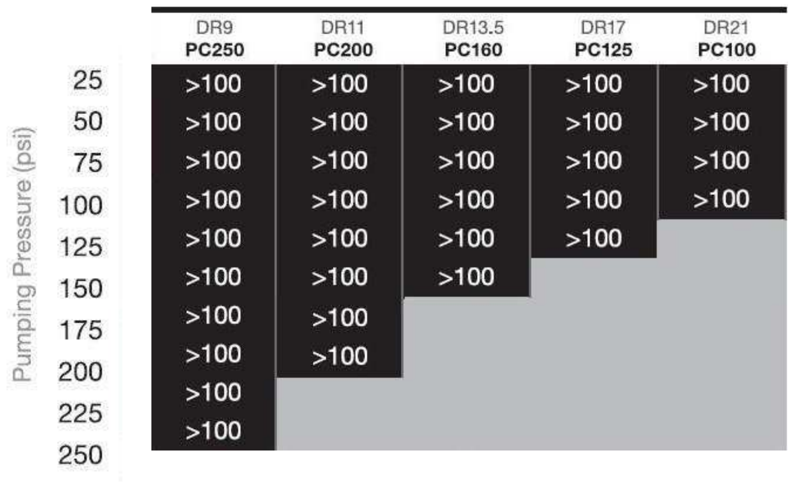
Figure 4 – Applied unit internal pressure (green = 0 kPa).

The following two load cases were analysed:

Load case	Description	Comments
1	Design pressure of 1,600 kPa at 20°C up to 50 years.	Use the valve pressure rating of 1600 kPa as design pressure.
2	Pressure surge raising internal pressure to 2,000 kPa at 20ºC up to 50 years.	Models the internal pressure, of 2000 kPa

3.4.1 Fatigue

Studies have shown that HDPE pipes are not susceptible to fatigue under typical municipal field conditions. Supplier data indicates fatigue lives of over 100 years for HDPE pipe when subject to 15 minute surge cycling due to 1.2m/s water flow. This is shown in the figure below which lists the estimated design fatigue life (based on a safety factor of 2) for Performance Pipe™ HDPE pipe.



Pumping Pressure (psi)	DR9 PC250	DR11 PC200	DR13.5 PC160	DR17 PC125	DR21 PC100
25	>100	>100	>100	>100	>100
50	>100	>100	>100	>100	>100
75	>100	>100	>100	>100	>100
100	>100	>100	>100	>100	>100
125	>100	>100	>100	>100	
150	>100	>100	>100		
175	>100	>100			
200	>100	>100			
225	>100				
250	>100				

Figure 5 – Working pressure rating and fatigue life, in years, for Performance Pipe™ HDPE piping. DR is the equivalent of the standard dimension ratio (SDR). Grey area indicates pumping pressure exceeds the working pressure.

3.5 Vessel classification

Non-metallic vessels are not classified

3.6 Vessel material

From AS/NSZ 1200-2000: *Pressure equipment*

Material must comply with AS, AS/NZS, ISO, EN, BS, ASME, ASTM or API material Standards which apply specifically to pressure equipment.

The material for this vessel was specified as high density polyethylene (HDPE) with AS 4130:2009 compound classification: PE 100. This material falls under AS 4131-2010: *Polyethylene (PE) compounds for pressure pipes and fittings.*

3.7 Material properties

The clamp was modelled as ductile iron grade 500-7 with a Poisson’s ratio of 0.275 and a Young’s modulus of 169 GPa. The flange was modelled as grade 316 stainless steel with a Poisson’s ratio of 0.29 and a Young’s modulus of 193 GPa.

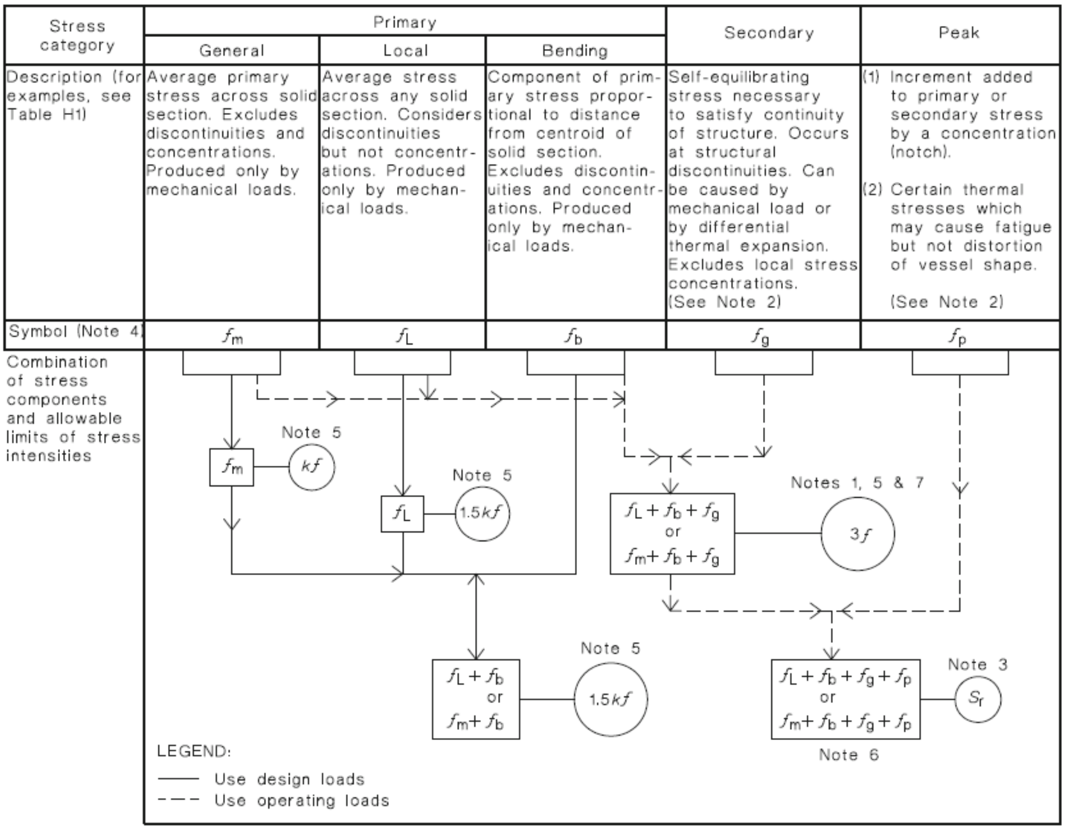
The valve body is fabricated from high density polyethylene (HDPE) with AS 4130:2009 compound classification PE 100. Although a constant value of Poisson’s ratio of 0.4 was used for all load cases, the modulus values used in the analysis depended on the duration of the applied load and the temperature of the valve body. This is discussed in more detail in the following sections.

The ring-bending modulus (Young’s modulus) was taken from Table 2.1 in AS 2566.1:1998 as being 260 MPa for PE 100. This is the long term (50 year) value used in calculating the allowable long term operating pressure.

4. ALLOWABLE STRESS

4.1 Allowable stress to AS1210 Figure H1

The stress classifications and limits of stress intensities are shown in AS1210 Appendix H, Figure H1, also shown in this document in Figure 6. This paragraph derives the allowable stress path from Figure 6.



Stress category	Primary			Secondary	Peak
	General	Local	Bending		
Description (for examples, see Table H1)	Average primary stress across solid section. Excludes discontinuities and concentrations. Produced only by mechanical loads.	Average stress across any solid section. Considers discontinuities but not concentrations. Produced only by mechanical loads.	Component of primary stress proportional to distance from centroid of solid section. Excludes discontinuities and concentrations. Produced only by mechanical loads.	Self-equilibrating stress necessary to satisfy continuity of structure. Occurs at structural discontinuities. Can be caused by mechanical load or by differential thermal expansion. Excludes local stress concentrations. (See Note 2)	(1) Increment added to primary or secondary stress by a concentration (notch). (2) Certain thermal stresses which may cause fatigue but not distortion of vessel shape. (See Note 2)
Symbol (Note 4)	f_m	f_L	f_b	f_g	f_p

Figure 6 - Stress categories

4.1.1 Peak stress category (f_p)

No stress concentrations are present, which are a possible cause of brittle fracture and thus not applicable.

4.1.2 Secondary stress category (f_g)

The vessel yields due to the mechanical loading (internal pressure), thus applicable.

4.1.3 Primary Stress category

The following stress categories were applicable to the analysis of the valve.

General (f_m)

Average stress through a section of the shell located away from discontinuities and stress concentrations.

Local (f_L)

Average local stress considering discontinuities but excluding stress concentrations.

Bending (f_b)

Caused by primary stress due to bending moment.

From the above stress intensity identifications as per Figure 6, the following equation applies for this case:

$$f_L + f_b + \ f_g \ \leq 3f$$

The allowable stress was taken as being equivalent to the allowable hydrostatic design stress (hoop stress) used in the design of HDPE piping, Figure 7. The design strength at 50 years applies, from Figure 7 is 10 MPa at 50 years. For AS1210 purposes the design strength of the material at 50 years and at 20° C, R_e will be taken as 13.7 MPa.

Where from AS1210 Appendix A, the design strength is:

$$13.7\ MPa \div 1.5 = 9.13\ MPa$$

Then from AS1210 Appendix H the allowable stress intensity is:

$$3f = 3 \times 9.13 = 27.4\ MPa$$

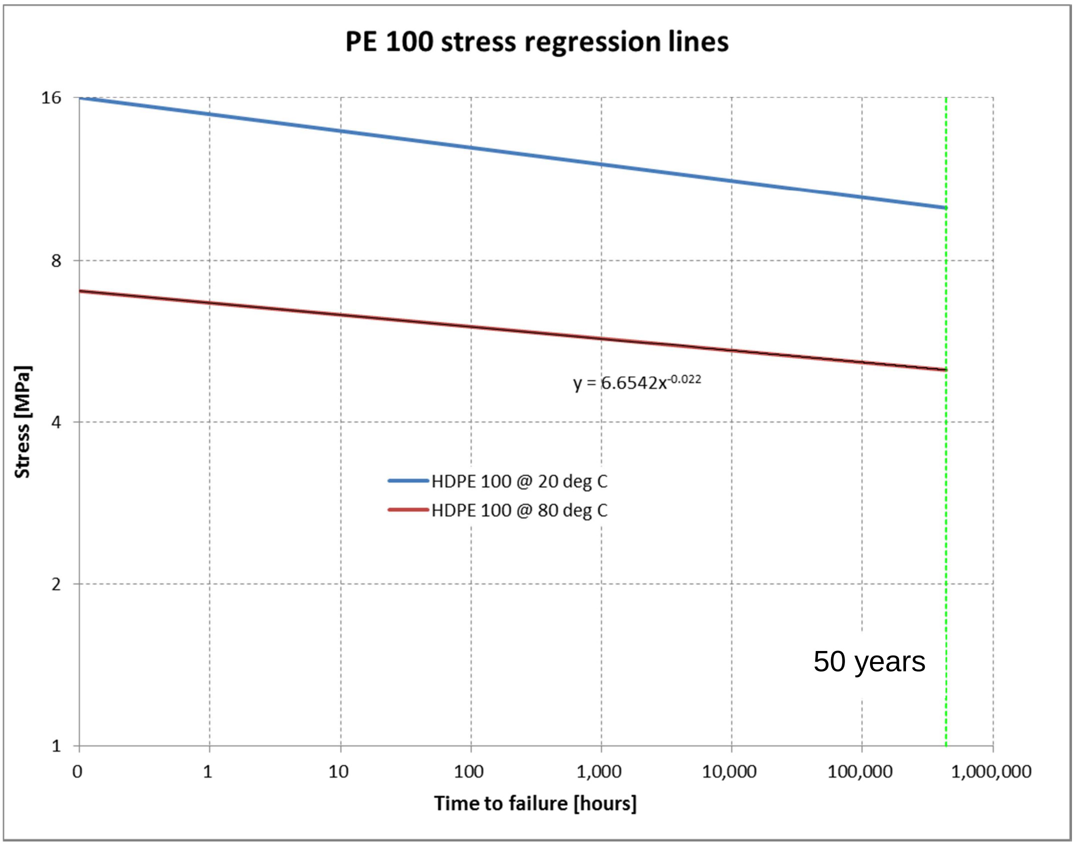


Figure 7 – Stress regression curves for PE 100 at 20ºC and 80ºC.

5. FEA RESULTS

The following load cases were assessed:

- Operating pressure of 1,600 kPa at 20° C for 50 years
- Surge pressure of 2,000 kPa at 20° C in year 50

The governing case was the Surge pressure case due to the higher internal pressure. The FEA reports Tresca stresses as $f_L + f_b + f_g$. The stresses reported in the results file were limited to 27 MPa in accordance with the calculated allowable stress.

5.1 Load case 1

Stress plots are shown in equivalent (Tresca) stresses shown in mega Pascals. The results indicate that for normal operation at 1,600 kPa with material properties of 50 year old PE100, that the stress limits are approaching the allowable stress limit. Therefore the valve should be replaced not later than 50 years after manufacture of the valve body material.

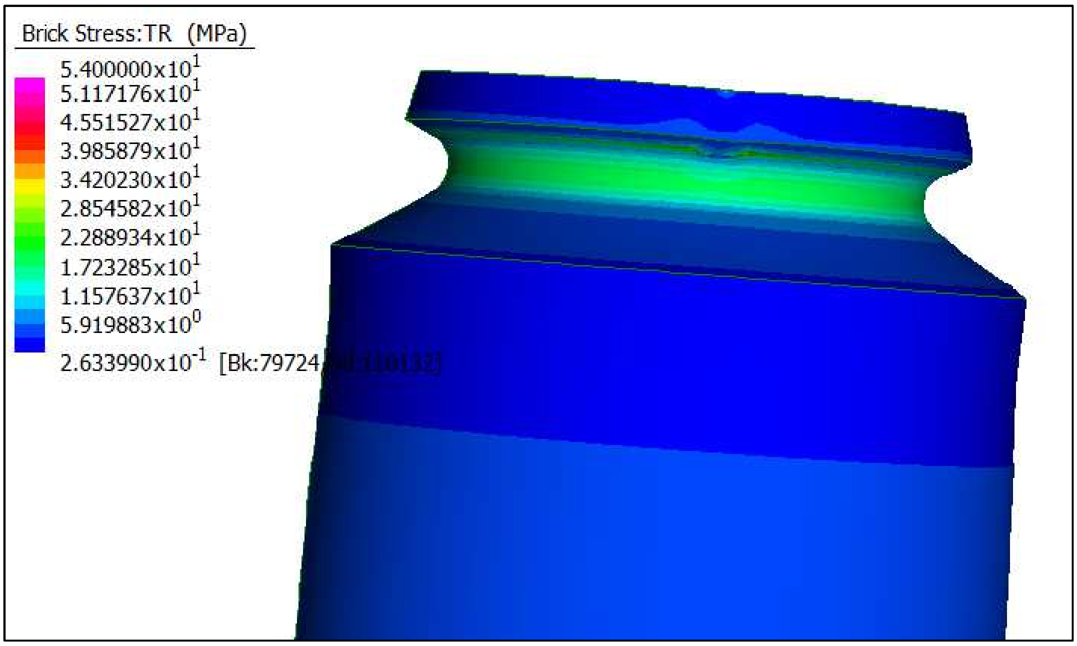


Figure 8 – Valve body equivalent stresses.

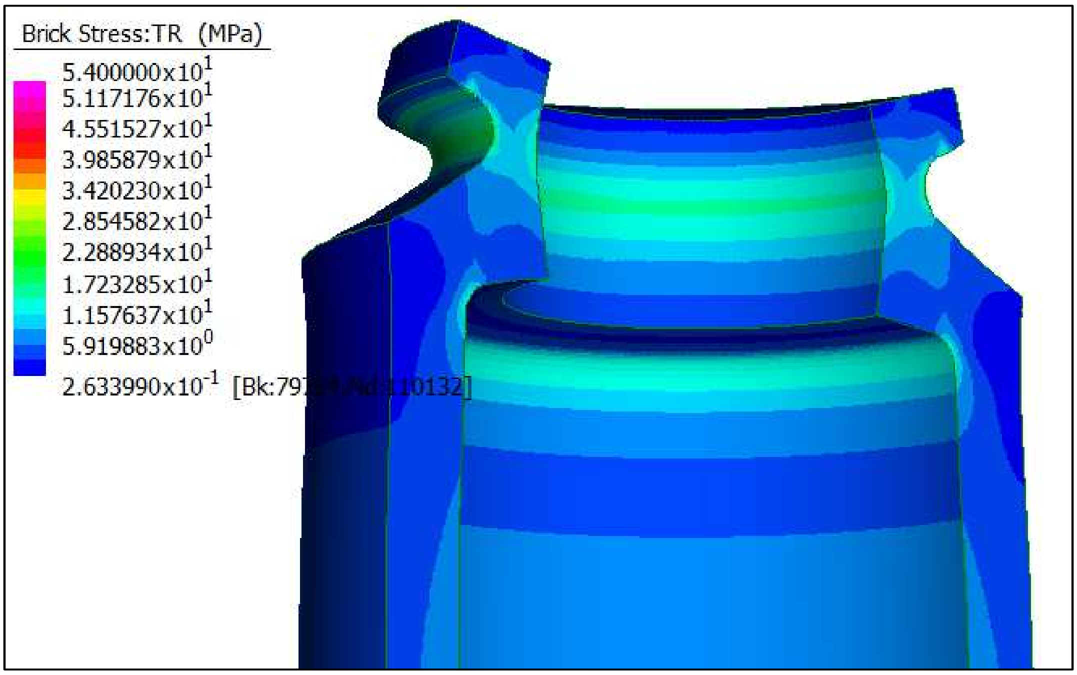


Figure 9 – Valve body equivalent stresses.

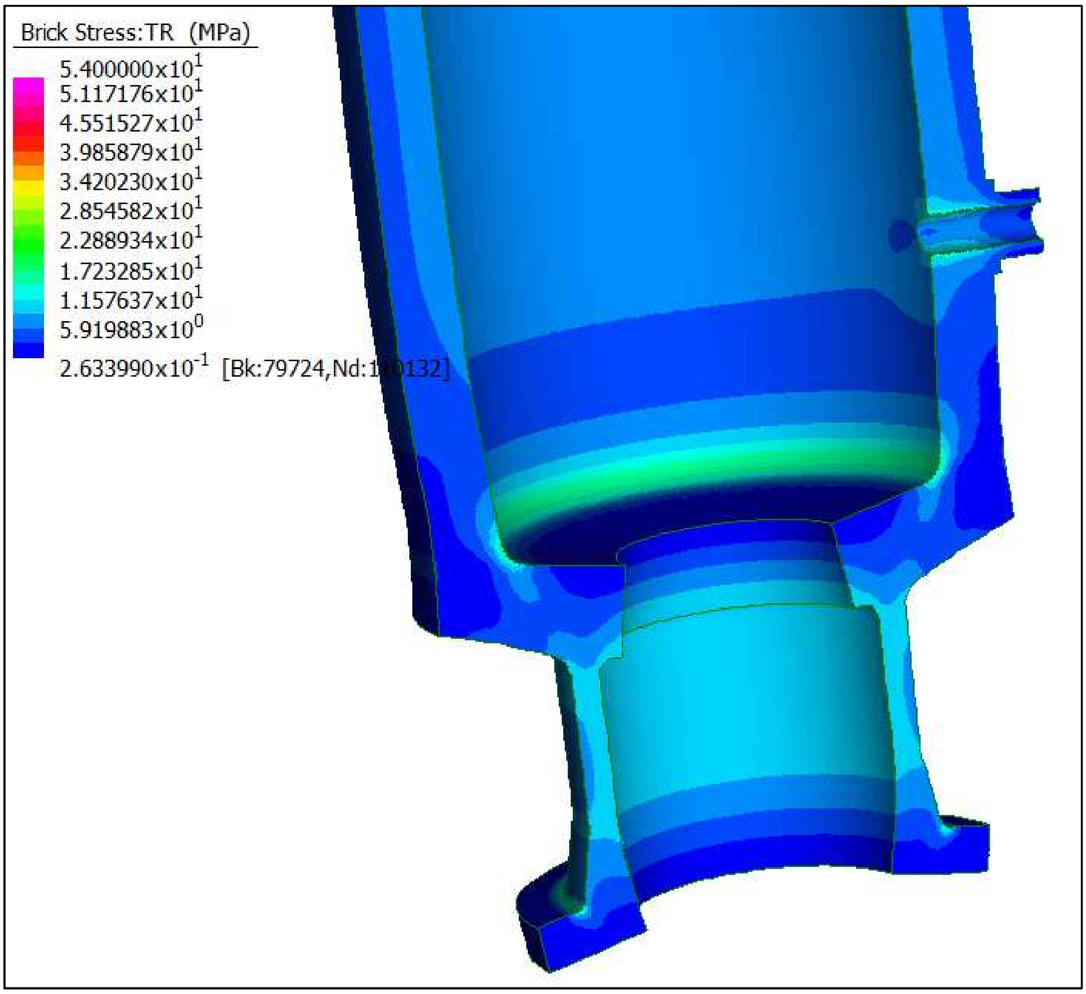


Figure 10 – Valve body equivalent stresses.

5.2 Load case 2

Stress plots are shown in equivalent (Tresca) stresses shown in mega Pascals.

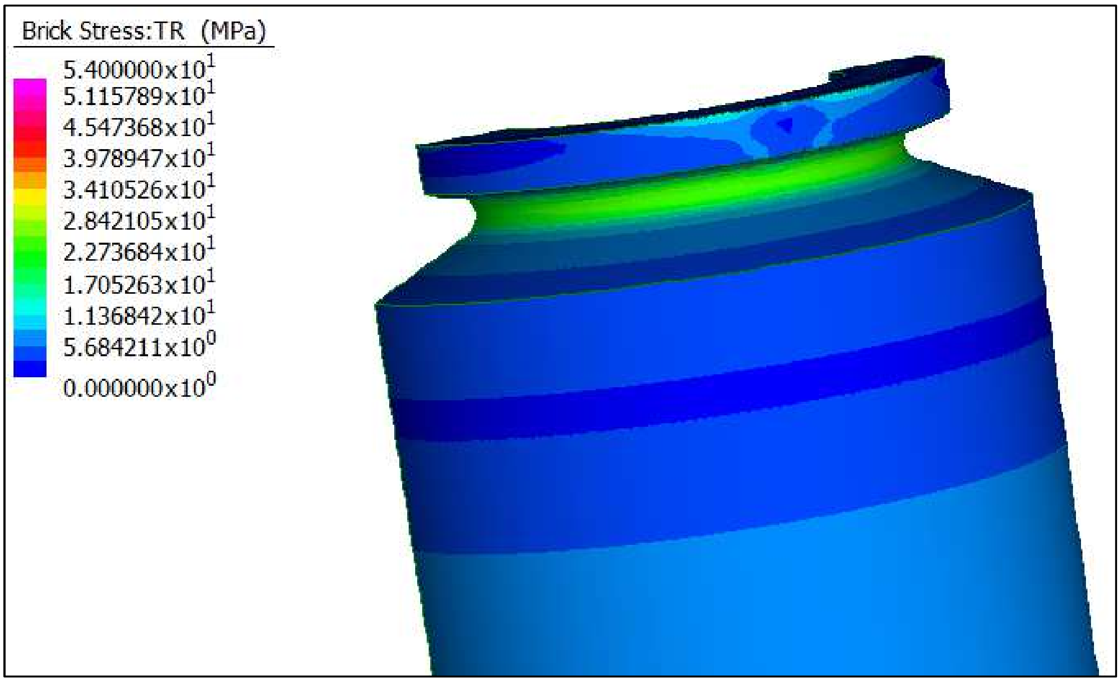


Figure 11 – Valve body equivalent stresses.

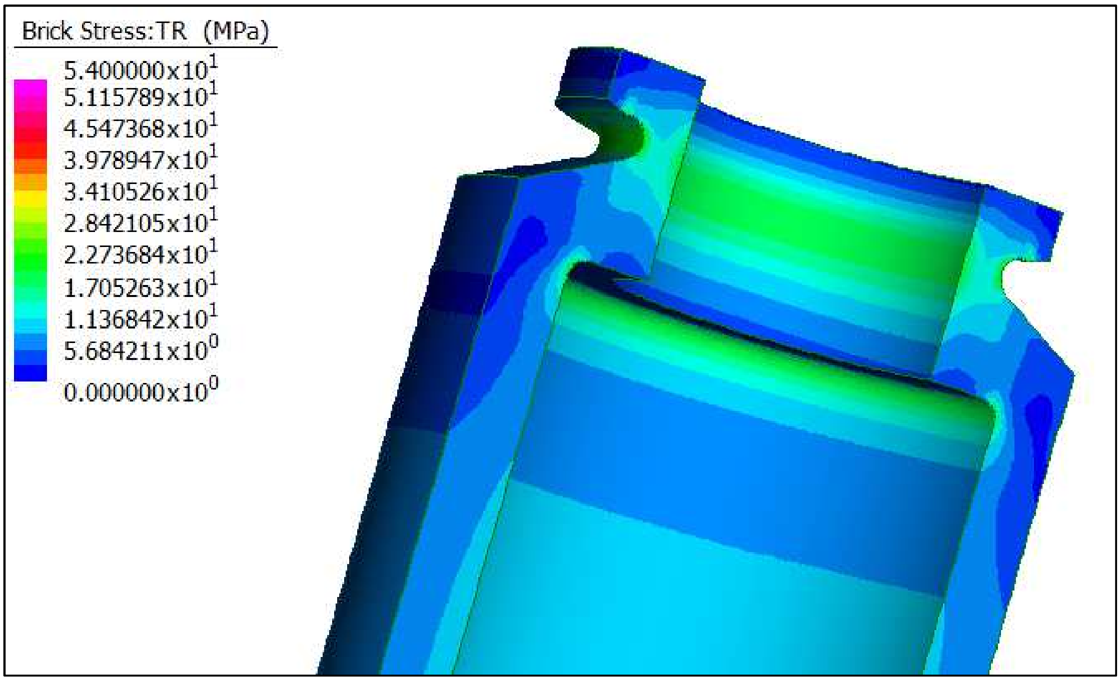


Figure 12 – Valve body equivalent stresses.

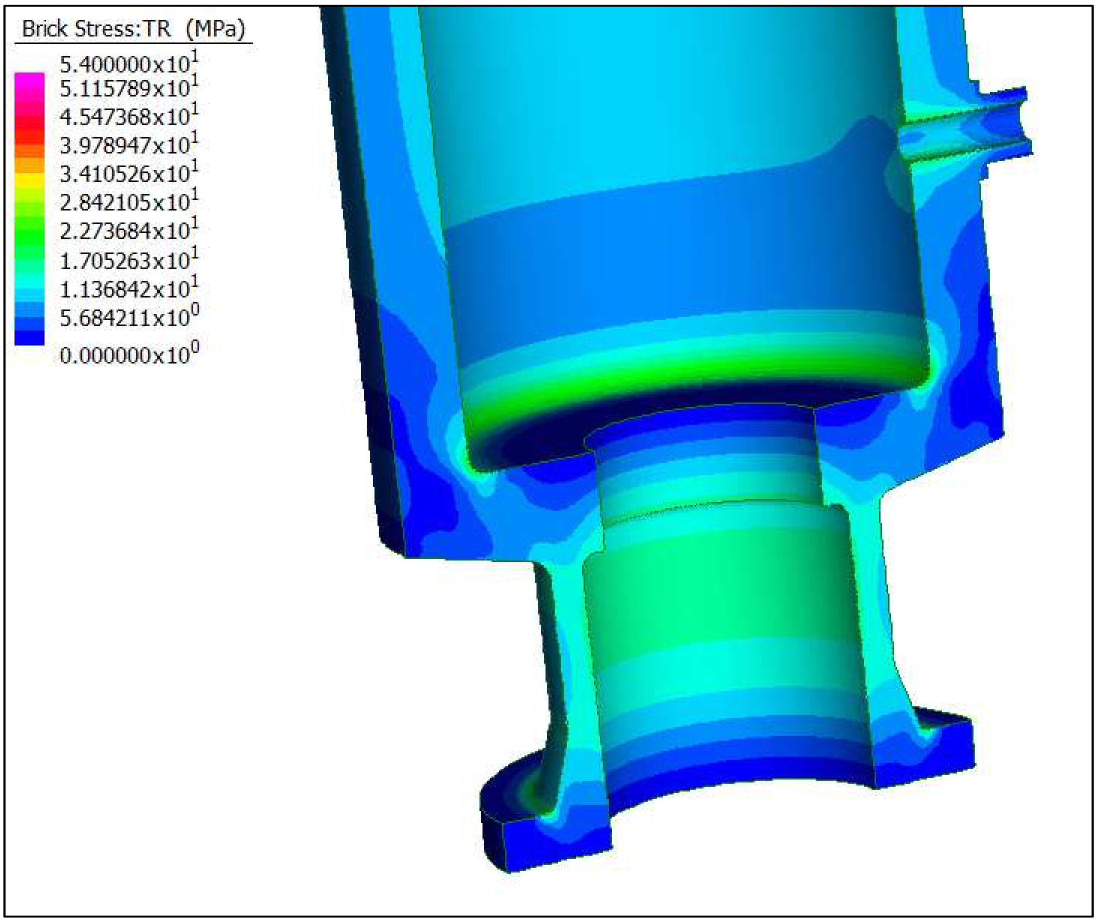


Figure 13 – Valve body.

6. DISCUSSION

6.1 Hand verification of results

Stresses calculated in the FEA were verified by hand for load case 1. Figure 13 shows main body wall stresses of approximately 6.8 MPa. Using the formula for stresses in thick walled pipes gave a stress of 6.3 MPa, a difference of 8% to the FEA stresses. The difference can be accounted for by the influence of the global valve geometry on the stresses where the thick walled pipe formula assumes a continuous circular cross section.

7. CONCLUSION

The strength of the body of the valve was assessed to AS1210-2010 Pressure Vessels and was found to be acceptable for a normal operating pressure of 1,600 kPa and a surge pressure of 2,000 kPa. The assessment was based on material properties 50 years after production, which limits the service life accordingly.