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Stress Analysis of IPS Pressure Vessel

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1. Description

This Study gives the detailed consideration of code acceptability for the main Class 1 components of the IPS for the Design & Test Conditions and Service Level D Condition. The first part in this study describes the allowable stress intensities in accordance with ASME III NB. The second part picks out the maximum stress intensities that have been calculated and compares these against the allowable values in accordance with ASME III NB requirements.

2. Stress Intensity Allowable

The strength properties in Table 2 are used to establish allowable stress intensities for the main IPS material, according to ASME III NB requirements, i.e. as a function of stress category and service level.

Table 1 Allowable Stress Intensities for IPS Material

Design	Pm	Pl	Pl+Pb
	Sm	1.5*Sm	1.5*Sm
Level A	**Pe**	**Pl+Pb+Pe+Q**	**Pl+Pb+Pe+Q+F**
	3*Sm	3*Sm	Sa
Level B	Pm	Pl	Pl+Pb
	1.1*Sm	1.1*1.5*Sm	1.1*1.5*Sm
Level C	Pm	Pl	Pl+Pb
	max 1.2*Sm, Sy	max 1.8*Sm,1.5*Sy	max 1.8*Sm,1.5*Sy
Level D	Pm	Pl	Pl+Pb
	min 2.4*Sm, 0.7*Su	min 1.5*2.4*Sm & 1.5*0.7*Su	min 1.5*2.4*Sm& 1.5*0.7*Su
Test	Pm	Pm+Pb	
	0.9*Sy	≤ 1.35 Sy (if Pm<0.67*Sy) ≤2.15*Sy-1.2*Pm (if Pm>0.67*Sy)	

For Design & Test Conditions, Service Levels A, B and C there are also special limits on triaxial stress (4.0 x Sm = 492 MPa at 350^{o}C), bearing stress (Sy = 136 MPa at 350^{o}C) and average primary shear stress for pure shear loading (0.6 x Sm = 73.5 MPa at 350^{o}C). For Service Level D there is also a special limit on average primary shear stress across a section for pure shear loading (0.42 x Su = 189.8 MPa at 350^{o}C)

3. Comparison of Maximum Calculated Stress Intensities against Allowable

Table 2 to Table 6 below compares the maximum stress intensities, as calculated by the finite element assessment against the code allowable

The maximum stress intensity in each component of the IPS is given for each combination of stress type.

3.1 Design Condition

Table 2 gives the main results for the Design Loadings. The areas of significant primary stress are the shell regions with the thinnest wall and the hubs of the inner pressure vessel and head flanges. The primary stresses in these areas are all within the code limit.

Table 2 Maximum Stress against Design Conditions

Component	Stress Category	Calculated Stress (MPa)	Allowable Stress (MPa)
Inner PV	Pm	94	123
	Pm + Pb	102	185
	Pm	111	123
	Triaxial	148.5	492
Outer PV	Triaxial	62	492
	Average bearing stress	116	207 (at 50^{o}C)
	Hub Stress, Sh	5	185
	Radial flange stress, Sr	14.3	123
	Tangential flange stress, St	97.4	123
	(Sh+Sr)/2	10.0	123
	(Sh+St)/2	50.5	123
IPS Head	Pm	78	123
	Pm	38	123
	Pm	64	123
	Pm + Pb	139	185
	Pm	72	123
	Triaxial	195	492
	Pm	79	123
	Pm + Pb	89	185

3.2 Normal Operation + SSE

The stress results for the SSE load include the Design Pressure stresses. The stress intensities for the two types of loading have been simply added. Since the SSE seismic stresses are slightly higher than the OBE seismic stresses. However that the Pm stress in the inner pressure vessel has been calculated in a more conservative way than that for the OBE

Table 3 Maximum Stress against SSE Conditions

Component	Stress Category	Calculated Stress (MPa)	Allowable Stress (MPa)
IPS Head	Pm + Pb	184	276
Inner PV	Pm	145 (Note 1)	184
	Pm + Pb	145	276
Outer PV	Pm + Pb	41	276

Note 1 The maximum seismic stress intensity of 34 MPa is (conservatively) assumed to be a membrane stress and is simply added to the stress intensity due to pressure. This is a conservative approach.

3.3 In-Pool Pipe Break

This case assumes a double-guillotine break at the hot leg nozzle weld. The FE results below show that although very high stresses can be expected in the outlet nozzle region the stresses in the inlet nozzle, the PV flange region (including the bolts) and the IPS Head below outlet nozzle level, will be well within the stress limits of ASME III Appendix F. Therefore such an accident will not prejudice the capability for emergency cooling of the fuel pins. The stresses in the PV flange region remain well within the Appendix F limits.

Table 4 Maximum Stress against Pipe Break Conditions

Component	Stress Category	Calculated Stress (MPa)	Allowable Stress (MPa)
IPS Head	Pm	79	184
	Pm + Pb	200	276
	Pm + Pb	145	276

3.4 Failure of Inner Pressure Vessel

Primary stresses in the IPS Head are almost identical to those Design Conditions. The stresses in the outer PV are within the stress limits for both Design Conditions and Service Level D (ASME III Appendix F).

Table 5 Maximum Stress against Failure of Inner Pressure Vessel Conditions

Component	Stress Category	Calculated Stress (MPa)	Allowable Stress (MPa)
IPS Head	Pm	38	184
	Pm	70	276
	Pm	72	276
	Pm	79	184
	Pm+ Pb	89	276
Outer PV	Pm	111	184

3.5 125% Hydrostatic Test

There is no reason for the pressure in the vessel during the hydrotest to exceed the test pressure (1.25 x 17.5 MPa) by more than 6% (see NB-3226(a)) so there is no code requirement to determine the stresses. However these have been determined below as a check. Table 6 summarises the results.

Table 6 Maximum Stress against Hydrostatic Test

Component	Stress Category	Calculated Stress (MPa)	Allowable Stress (MPa)
IPS Head	Pm	98	186
	Pm	93	186
	Pm + Pb	106	221
Inner PV	Pm	139	186
	Pm	117	186
	Pm + Pb	127	279

4. Conclusion

This study shows the integrity of the pressure retaining parts of the IPS design against ASME III Sub-Section NB, i.e. Class 1, requirements for the Design & Test Conditions and Service Level D Condition. The results are summarized by Tables 2 to 6. The overall conclusion is that the pressure retaining parts of the IPS design meet the code requirements.

REFERENCES

[1] ASME Boiler and Pressure Vessel Code, Section III NB, 2001
[2] ASME Boiler and Pressure Vessel Code, Section II, Part D, 2001.
[3] Determination of Thermal and Pressure Loads on IPS Pressure Vessel Assembly, HAN-FL-E-310-RT-R006, Rev. 0, 2005
[4] ABAQUS v6.4 User Manuals, ABAQUS Inc., 2003.