Seismic Analysis of the In-Pile Test Section

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1. Introduction

This study gives the results of the seismic analysis of the IPS (In Pile Section) with lower bracket support. The results cover the natural frequency and seismic response of the IPS for the SSE and OBE events. An FE (Finite Element) model which includes the two vessels of the IPS and its support structure were analyzed by ABAQUS.

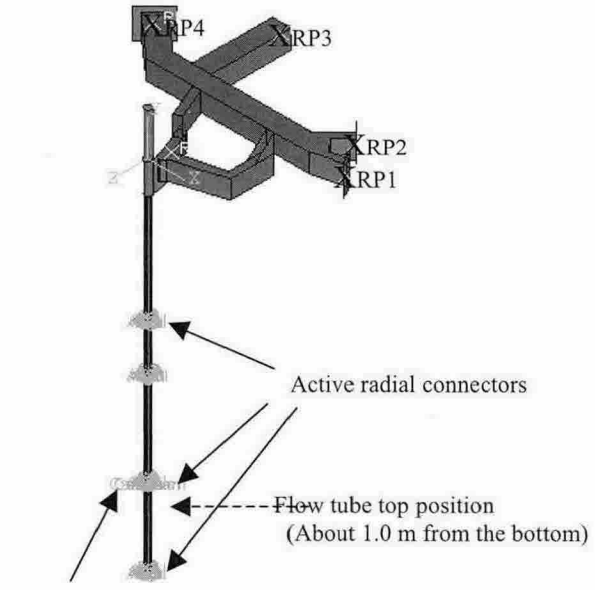


Figure 1. FE model of IPS for Seismic analysis

2. Input parameters

Fig.2 shows the arrangement of the IPS support tube, outer pressure and inner pressure vessels. Model dimensions were shown Table 1

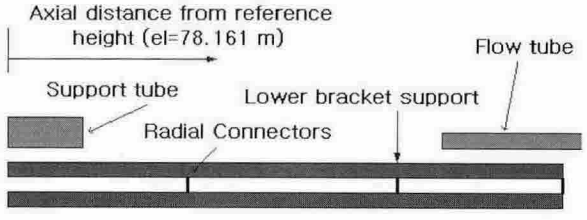


Figure 2. IPS Vessel Geometry

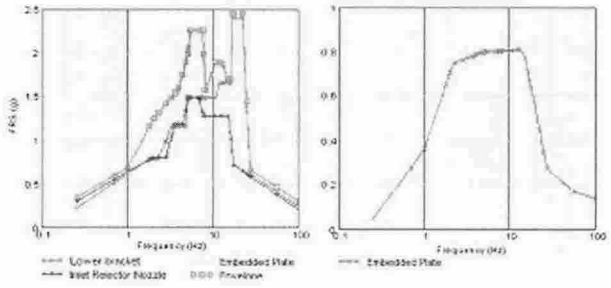
Non-structural mass has been added as follows:
- Inner assembly and its internal water.
- Mass of outer vessel's external water.
- Internal and external water for box beam.
- A 100 kg concentrated mass for coupling housing

The required inputs are SSE with 2% damping and OBE with 1% damping. In order to implement the response spectrum method, it is necessary to adopt a procedure for combining inputs from different directions and from different vibration modes. The procedure used here is:
- Combination of the directions using the SRSS
- Combination of the modes using the 10% method.

Table 1 Dimension of IPS

Parameter	Value
Support tube ID/OD	83/120 mm
Support tube length	0.4 m
Outer pressurevessel ID/OD	58/68 mm
Inner pressure vessel ID/OD	46/54 mm
Radial connector positions	-1.85m, -3.687 m,-4.768 m
Lower bracket support position	-3.687 m.

2.1 SSE events



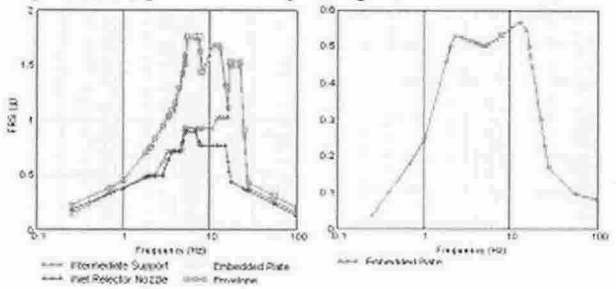
(a) (b)

Figure 3. Seismic Input (SSE Horizontal & Vertical)

Fig.3 (a) shows the envelope slightly lifted to illustrate the underlying curves. This enveloping approach is conservative, but not overly so here. Fig.3 (b) shows the corresponding inputs for the vertical direction (Y). Compared to the horizontal case, the inputs here are less.

2.2 OBE events

Fig.4 (a) , (b) give the corresponding results for the OBE



(a) (b)

Figure 4. Seismic Input (OBE Horizontal & Vertical)

3. Analysis

Table 2 shows the results of the natural frequency analysis for the significant modes below 100 Hz by listing the mode frequencies and participating masses. These masses indicate the amount of coupling in each mode with the supports: modes with low participating mass would not couple even if the input was significant at the modal frequency. Note also that, as the seismic input is low for frequencies above about 30 Hz, modes 7 and higher do not contribute significantly to the IPS response.

Table 2 Natural frequency results

Mode	Freq. (Hz)	Mass in X (kg)	Mass in Y (kg)	Mass in Z (kg)
1	11.6	1	2	93
2	11.6	93	0	1
3	26.5	0	145	0
4	27.2	1	0	0
5	29.8	1	504	10
7	33.3	0	17	2
10	44.1	55	0	1
11	44.6	0	15	19
12	55.4	359	5	30
Last mode <100 Hz	93.3	1	101	15
Total modes < 100Hz		542	1394	208

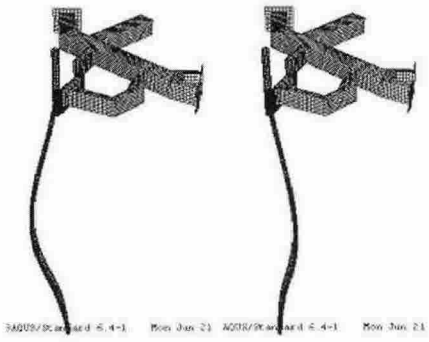


Figure 5. Vibration modes 1 and 2 (11.6 Hz)

The seismic stresses are predominantly axial stresses due to bending of the IPT and OPT about their centre-line axes. Hence the Tresca and axial stresses are similar. The peak stress occur at the top of the OPT and IPT as this region acts as cantilever support for the pressure tubes. The actual peak stresses will be less than those found in the seismic FE model since the model represents the pressure tubes as simple uniform tubes with an abrupt change where they connect to the head. Fig. 6 shows axial stress in the high stress region towards the top of the pressure vessel.

Table 3 Seismic results for deflection and stress

Parameter	*SSE*	*OBE*
Max. deflection at position of flow tube (mm)	1.79	1.63
Max. deflection at lower bracket support (mm)	1.70	1.49
Maximum deflection (mm)	6.90	6.08
Max. relative deflection between inner and out pressure vessels (mm)	0.6	0.5
OPT Stresses (MPa)		
Membrane stress (Tresca)	37	32
Membrane plus bending (Tresca)	41	35
Triaxial stress	17	14
IPT Stresses (MPa)		
Membrane stress (Tresca)	31	26
Membrane plus bending (Tresca)	34	29
Triaxial stress	13	11

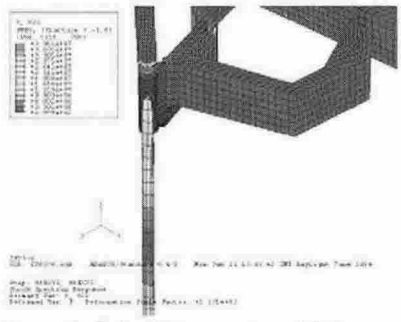


Figure 6. Seismic response axial stress

4. Conclusion

1. The lowest natural frequency of the IPS is 11.6 Hz and corresponds to lateral bending of the pressure vessels.
2. Seismic response deflections at the top of the flow tube (1.79 mm (SSE) and 1.63 mm (OBE)) are well within the 3.2 mm limit imposed by the proximity of adjacent fuel positions.
3. Seismically induced stresses are generally low, but must be combined with pressure stresses in order to assess the total reserve factors.

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