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BARCOM Round Robin Analysis: FORTUM pre test report

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1 ABSTRACT

In this report a preliminary mid-term analysis of the BARCOM test model is presented. The BARCOM test model is a 1:4 scale of an existing pressurized heavy water reactor (PHWR) pre-stressed concrete inner containment of 540 MW Tarapur Atomic Power Station 3&4 units in India. The goal of this mid-term analysis is to illustrate the modelling approach and achieve a prediction of the failure mode. The analysis was carried out using ABAQUS/CAE and ABAQUS/EXPLICIT version 6.7-EF1 software. In the analysis explicit time integration was used such way that the solution was quasi static. For the concrete material presentation the brittle cracking model available in ABAQUS/EXPLICIT was adopted. In the brittle cracking model the value used for the ultimate tensile stress was 3.6 MPa which is slightly higher then the value specified in the BARCOM documentation. The Young's modulus and Poisson's ratio used for concrete were 30 GPa and 0.2, respectively. The tendons were assigned ideal plastic von Mises material model with 1.683 GPa yield stress. The Young's modulus and Poisson's ratio used for tendons were 190 GPa and 0.3, respectively. The mesh of the containment consists of 4 -node quadrilateral and 3 -node triangle general purpose elements. In the analysis the bottom edge of the containment is fixed.

2 INTRODUCTION

This paper presents the modelling approach adopted by the authors in the BARCOM round robin analysis project.. The BARCOM test model is a 1:4 scale of an existing pressurized heavy water reactor (PHWR) pre-stressed concrete inner containment of 540 MW Tarapur Atomic Power Station 3&4 units in India [1].

The goal of this report is to present a description of the FEM model used for analysis, estimate the cracking behavior of the containment and provide plots of the essential results of some of the specified sensor locations (SSL).

3 FEM -ANALYSIS MODEL

3.1 General

The analysis was carried out using ABAQUS/CAE and ABAQUS/EXPLICIT version 6.8-1 softwares [2]. In the analysis explicit time integration was used such way that the solution could be interpreted as quasi-static. In other words, the loading was applied so slowly that the inertial effects were negligible.

The containment geometry was modeled with 3-node triangular shell elements and it is illustrated in Figure 1.

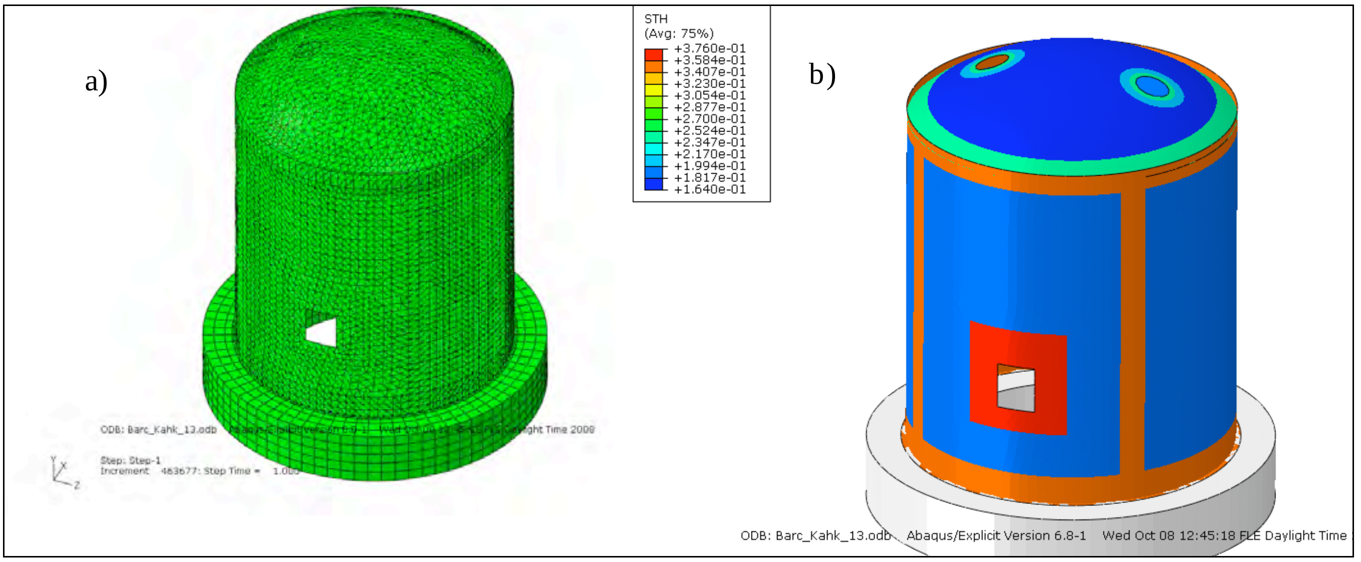

Figure 1. BARCOM testmodel FEM model (a) and shell element thickness map (b).

The containment geometry model includes two steam generator (SG) openings in the dome, emergency air lock (EAL) opening on the east side of the cylinder and the main air lock opening (MAL) on the west side of the cylinder. The foundation was modeled with 8-node solid elements.

The tendons were modeled with 2-node truss elements and in the analysis they were tied to the containment shell element surface. The tendon element layout is shown in figure 2.

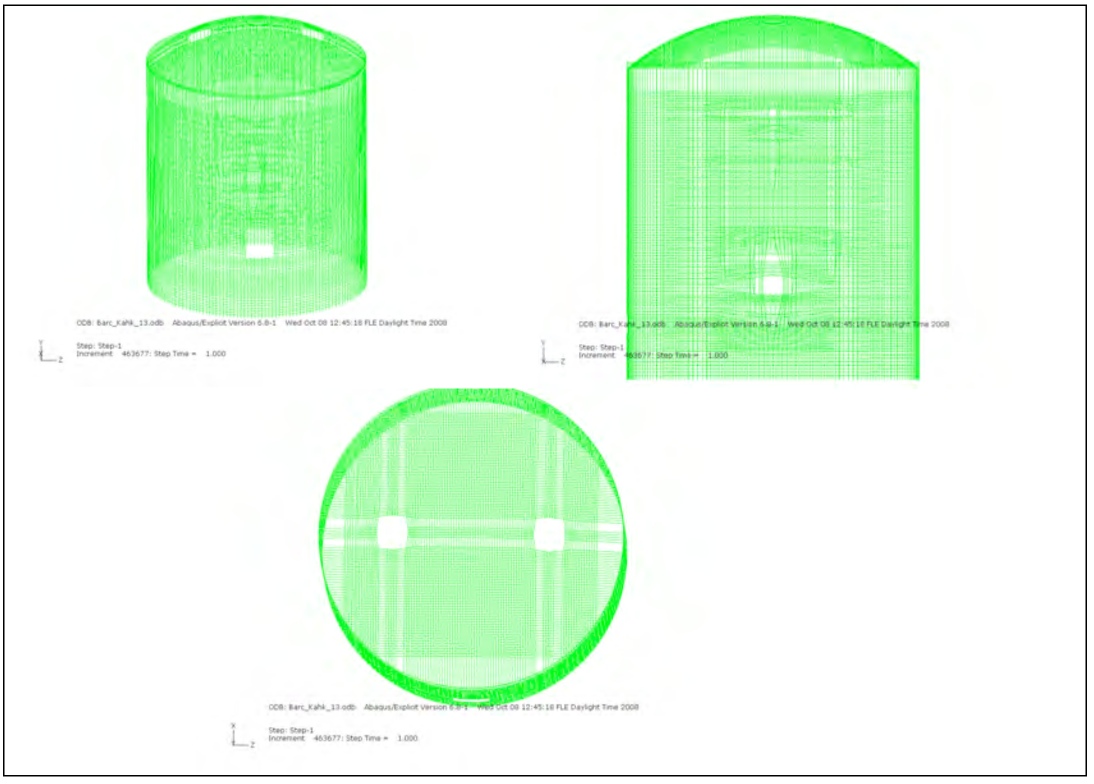

Figure 2. Tendon modeling with 2-node truss elements.

Pre-tension in the tendons was modeled using heat expansion. The heat expansion was utilized so that the nominal tensile stresses in the tendons were 80% of the tendon ultimate stress (0.8×1848 MPa $\approx$ 1478 MPa).

The FEM model consist of 27 416 nodes and 31 486 elements.

3.2 Material Properties

For the concrete material presentation the brittle cracking model available in ABAQUS/EXPLICIT [2] was adopted. In the brittle cracking model the fracture energy of 120N/m was used. The Young's modulus and Poisson's ratio used for concrete were 30 GPa and 0.2, respectively.

The tendons were assigned von Mises material model and strain hardening behavior was derived from the tendon load-elongation curve defined in the reference [1]. The Young's modulus and Poisson's ratio used for tendons were 190 GPa and 0.3, respectively.

We didn't model the rebars explicitly because it was thought that concrete material model implicitly contains the effect of the rebars.

3.3 Load

The analysis consists of two steps. In the first step tendons were tensioned to their pre-tension state and the gravity was introduced to the model. The time span of the first step was 1 s.

In the second step the internal over pressure was linearly raised to the value of 0.32 MPa. The time span of the second step was 2 s.

4 RESULTS

4.1 Cracking behavior of the containment (Figures 3 - 10)

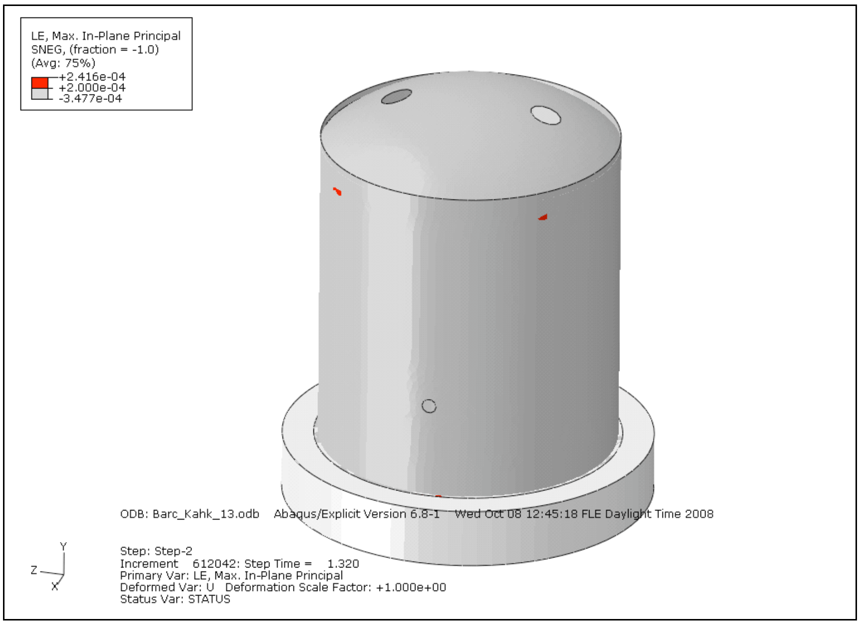

Figure 3. Appearance of surface cracks (red color) at 0.21 MPa over pressure.

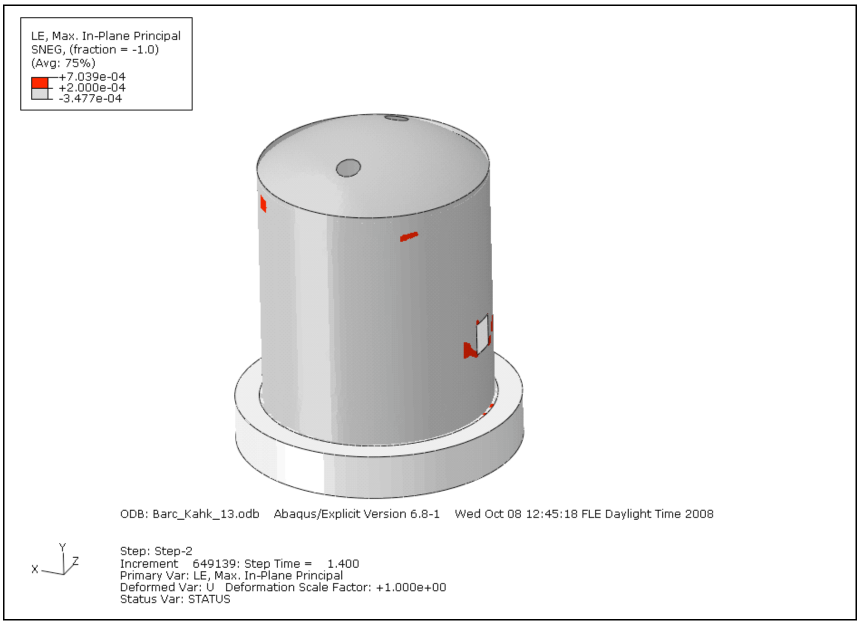

Figure 4. Surface cracks at 0.224 MPa over pressure.

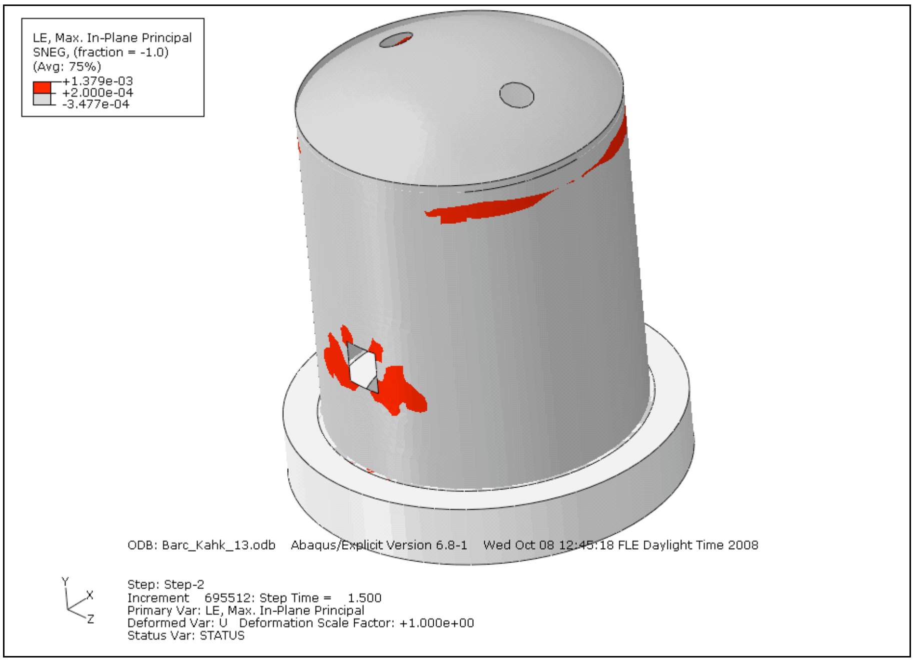

Figure 5. Surface cracks at 0.24 MPa over pressure.

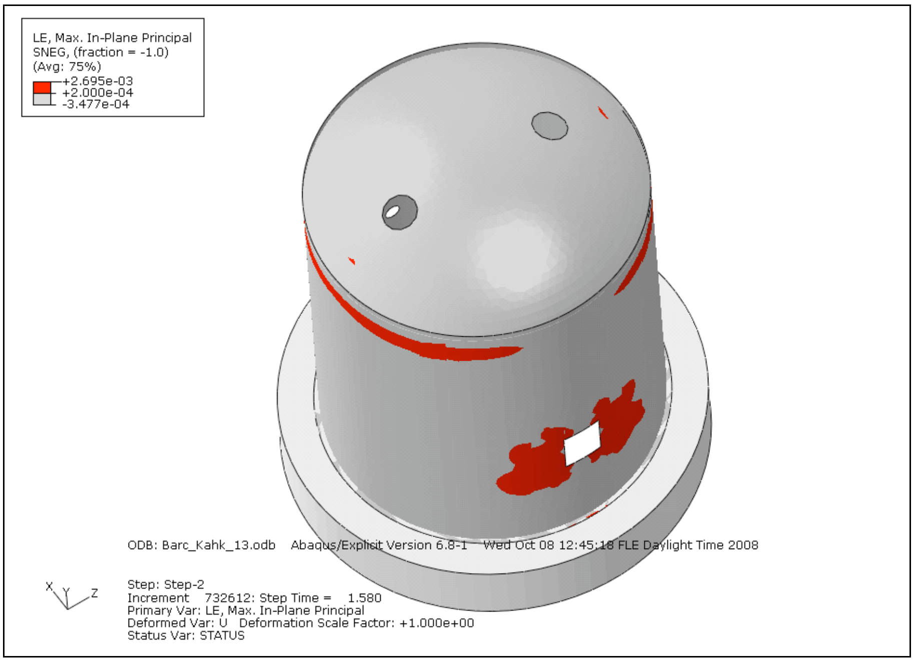

Figure 6. Surface cracks at 0.253 MPa over pressure.

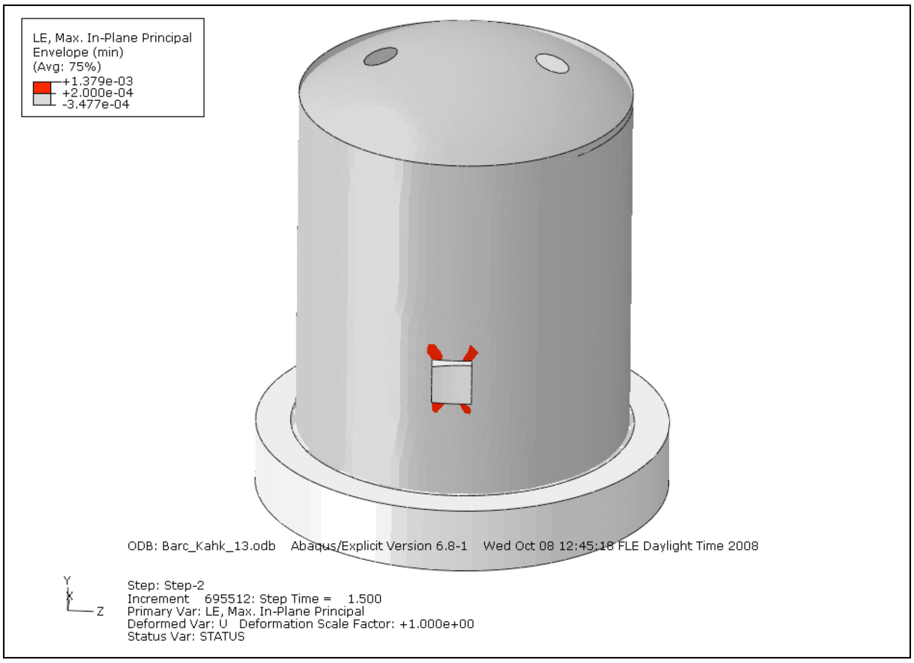

Figure 7. Through wall cracks at 0.24 MPa over pressure.

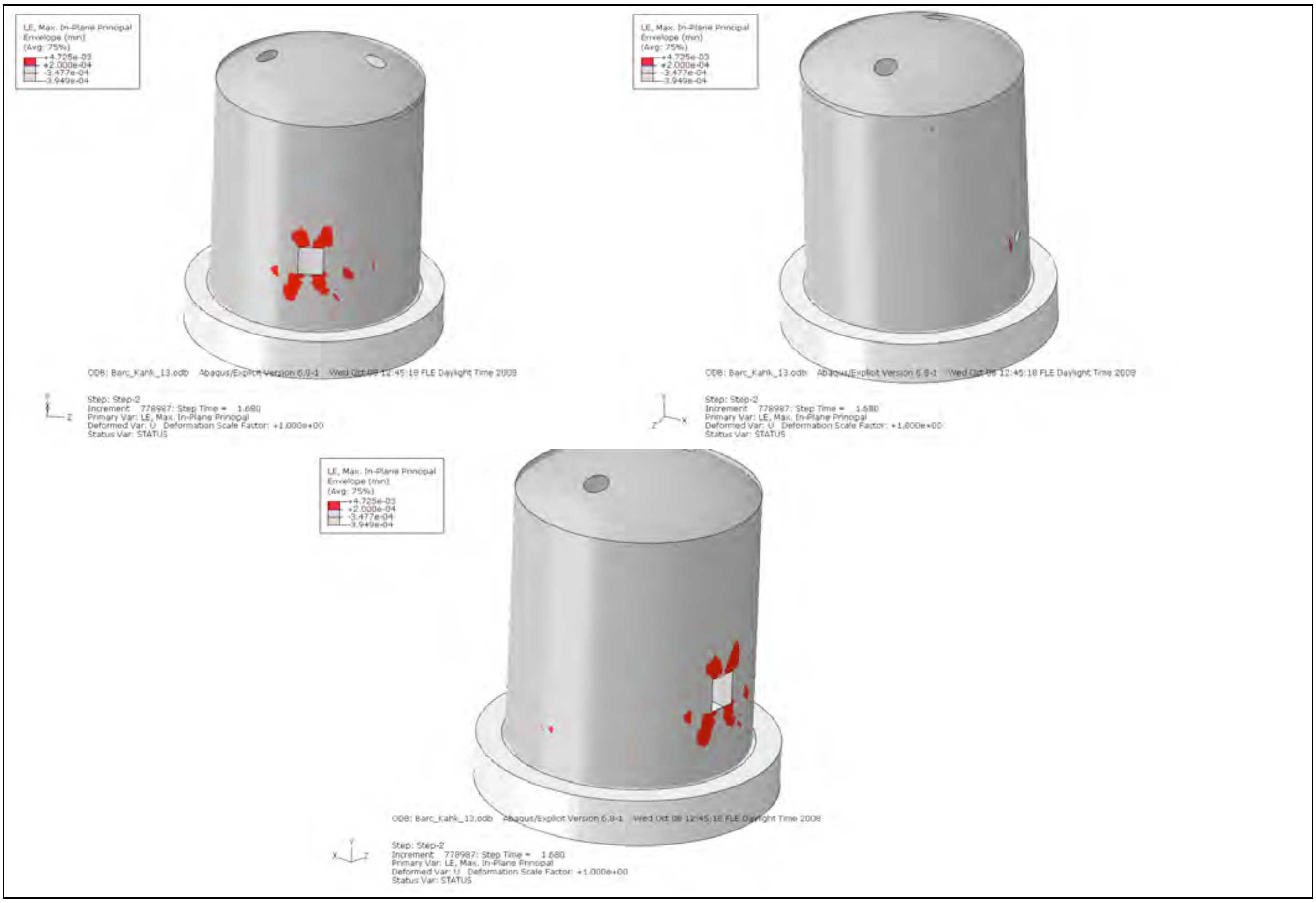

Figure 8. Through wall cracks at 0.27 MPa over pressure.

4.2 Failure modes

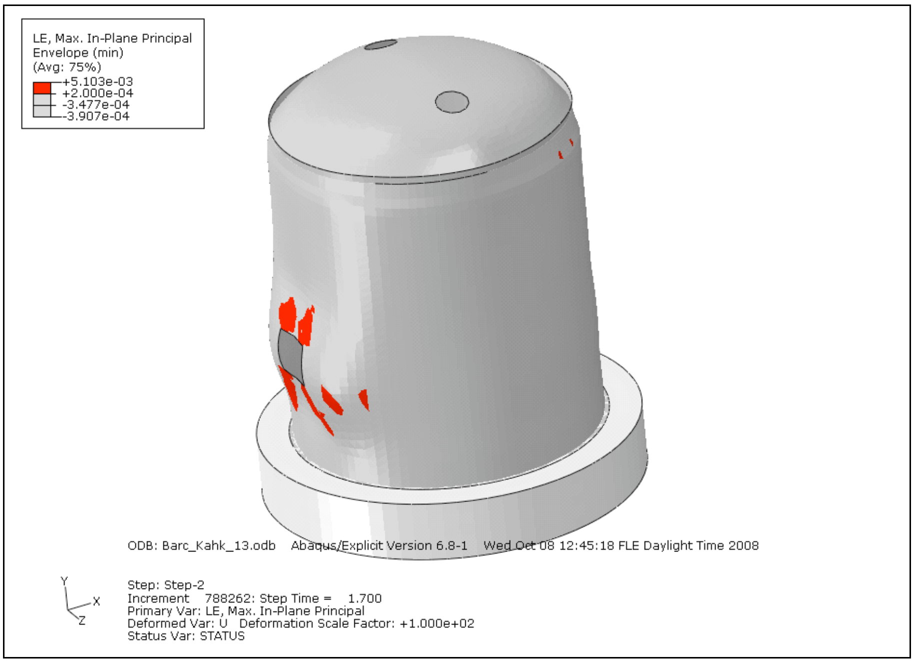

Figure 9. Failure mode at 0.272 MPa over pressure. Read color indicates through wall cracks. Deformation is scaled by 100.

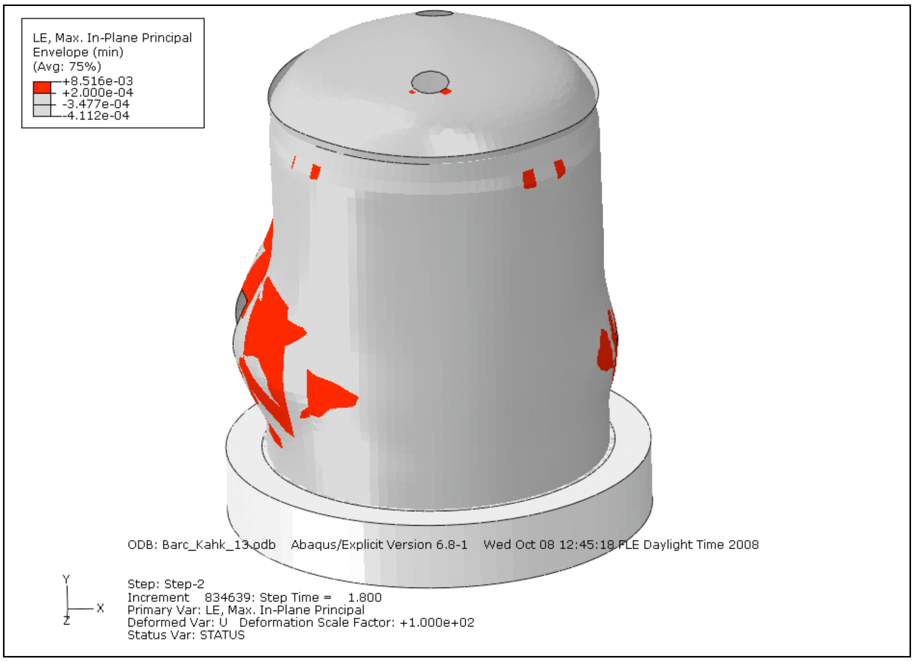

Figure 10. Failure mode at 0.288 MPa over pressure. Read color indicates through wall cracks. Deformation is scaled by 100.

4.3 Selected plots at specified sensor locations (SSL)

The location of selected SSL and their measurement directions are presented in Figure 11. Calculation results of those SSL can be seen in Figure 12.

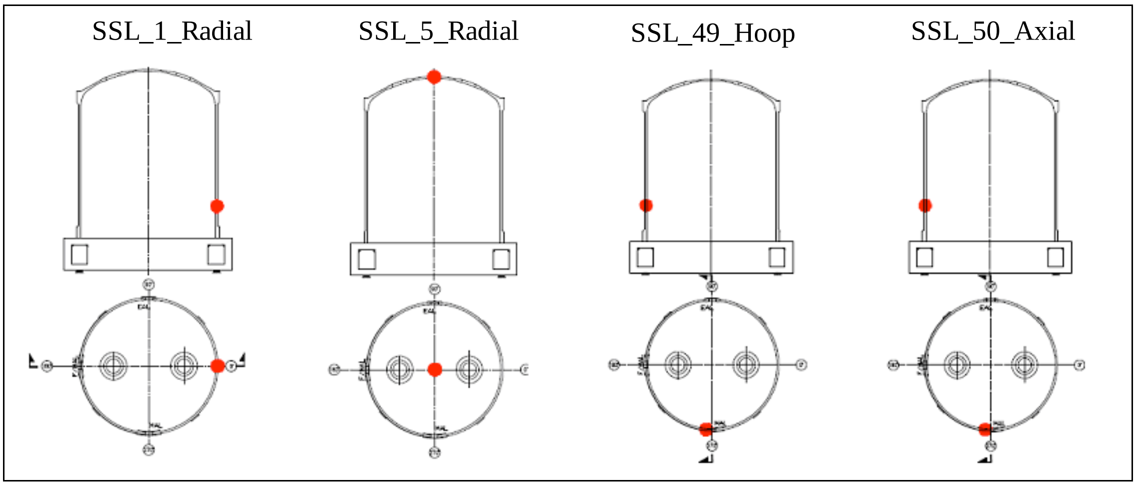

Figure 11. Sellected SSL location and the measurement directions. SSL 49 and 50 are measured below main airlock opening

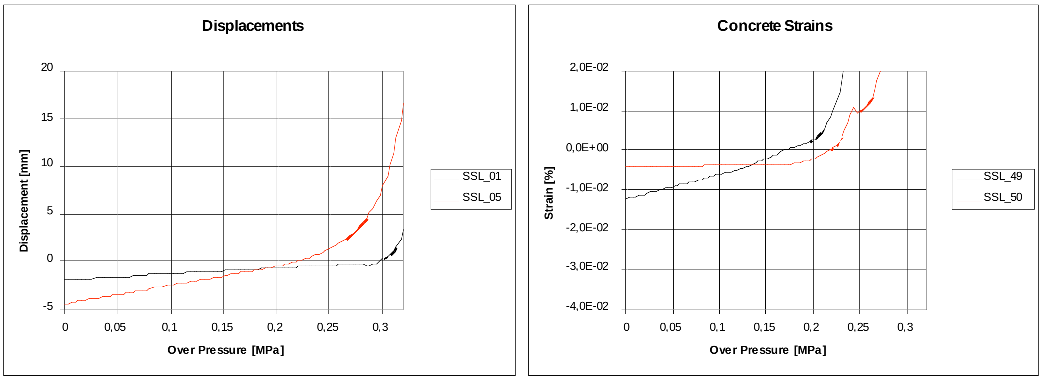

Figure 12. Results for the selected SSL

5 CONCLUSIONS

Based on the cracking estimates the first surface cracks appear at 0.21 MPa over pressure at the upper part of the cylinder. The containment starts to leak at 0.24 MPa over pressure. Leaking site is at the corner of the main air lock opening. It seems that the cylinder is under going catastrophic failure before the dome cracks appear.

Based on the SSL plots the first concrete strain nonlinearities occur at ca. 0.2 MPa over pressure at SSL_49 (hoop strain).

Based on this analysis our estimate for the ultimate collapse pressure of the containment model is **0.24 MPa**.

REFERENCES

[1] BARC Containment Model Round Robin Analysis, Model Documents, Mumbai, India, 2007

[2] ABAQUS version 6.8-1, Users Documentation, Simulia Inc., Dassault Systems, 2008