SMiRT-12 / K. Kussmaul (Editor)

U07/5

SBWR - DRYWELL HEAD ULTIMATE PRESSURE CAPABILITY

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1. INTRODUCTION

As part of the SBWR Design Team activities, Ansaldo has been involved with the prediction of the ultimate pressure capacity and of the leakage behaviour of the Drywell Head, under assumed pressure and thermal severe accident conditions; this is an important item for the probabilistic risk analysis of the plant, since large operable penetrations like the Drywell Head are generally critical locations of the primary containment, i.e. of the last engineering barrier to the release of radioactive material.

In general, elevated temperatures and pressures assumed for severe accident scenarios imply that ultimate strength capability be evaluated with proper consideration of material non linear behaviour and that the leakage potential be investigated with a careful analysis of the relative position of the sealing surfaces and of the performance of the seal material; for such purpose, after a brief presentation of the reference configuration of the SBWR Drywell Head, typical beyond design pressure and temperature severe accident scenarios will be indicated. Modeling and analysis procedures suitable to provide temperature dependent pressure ultimate capabilities and pressure and temperature dependent leakage characteristics will be outlined.

Calculated results will be evaluated against assumed shell and flange failure criteria, gasket sealing characteristics and allowable leakage rates.

2. STRUCTURAL ARRANGEMENT

Main characteristics of the SBWR reinforced concrete containment including its top slab have been already presented in Refs. /1/ and /2/.

The structural arrangement of the Drywell Head (D.H), which is a large operable penetration located with an inside diameter of 9.1 m at the RCCV Top Slab center, is shown in fig. 1. It consists of a 2 : 1 ellipsoidal, 40 mm thick steel dome, a 50 mm cylindrical section partially embedded into the concrete top slab, and connecting flanges and pretensioned bolts.

ASME SA 537 - Class 1 carbon steel material with stainless steel cladding has been selected for the shell, ASME SA 182 - F 304 stainless steel for flanges and ASME SA 320 - L 43 for the 72, 63.5 mm diameter, connecting bolts.

3. SEVERE ACCIDENT SCENARIOS AND ACCEPTANCE CRITERIA

Severe accident scenarios in terms of slow continuous increases of both containment internal pressure and bulk steam temperature have been considered. In order to evaluate the temperature effect on the predicted pressure ultimate capacity of the D.H., several cases, characterized with different steady state steel wall temperature distributions, have been investigated.

For each case the corresponding ultimate pressure capacity has been determined with the failure criterion defined in ASME code Section III, Div. 1, Subsection NB, paragraph 3213.25 in that the collapse load at a given location is defined as the intersection of the load-deflection curve and the collapse limit line (forming angles Θ and ϕ with the ordinate axis respectively, with $\phi = \arctan(2 \tan \Theta)$).

4. THERMAL ANALYSIS

Several thermal analysis with both one and two dimensional models have been performed to determine the resulting wall temperature distributions.

For each assumed steam bulk temperature case, the internal pressure effect on the heat transfer mechanism of the inside wall surface has been taken into account as well as the presence of external fuel auxiliary pool water. The environmental conditions in the water were assumed at atmospheric pressure and saturation temperature for long term conditions.

For the steel shell not backed by concrete, an automatic iterative one dimensional procedure has been set up to establish the convection mechanism and corresponding heat transfer coefficients at inside and outside the D.H. (such as natural convection, film steam condensation, water nucleate boiling). The results have been used as boundary conditions for subsequent two dimensional finite element thermal analysis aiming to provide temperature distributions not only on the shell wall but also in the connecting flange region and at the gasket location.

It has been found that, as a consequence of the cooling effect of the outside water covering the D.H., the surface temperature is always lower than the steam saturation temperature and it is governed by the assumed internal pressure, instead of the steam bulk temperature.

Four different thermal cases have been considered for the ultimate pressure evaluation: a first case at ambient temperature and three cases characterized with containment internal pressures equal to about one, two or three times its design pressure of 3.85 Kg/cm^2 (55 psig), leading to max inside surface temperatures of about 140, 174 and 190 °C respectively.

5. THERMOMECHANICAL FINITE ELEMENT MODEL

For the evaluation of pressure and temperature induced stresses and strains the detailed axisymmetric ANSYS model shown in fig. 2 has been used.

Major features of the model included shell and flange material plastic behaviour, equivalent orthotropic properties of the flange hole region, explicit modeling of connecting bolts with specified pretensioning forces and special interface non linear gap elements along the flange mating surfaces to detect any gap opening effect.

Due to the non linear nature of the used model, a Newton - Raphson iterative solution has been adopted by applying loads with progressive steps, starting from the bolt preload phase, followed with the thermal loads and completed with the internal pressure loads. Lower load increments have been applied when reaching first material yielding to preserve convergence of the solution.

Radial displacements and rotations induced at the anchor into the concrete containment Top Slab have been imposed as boundary conditions obtained from a separate containment analysis.

6. ULTIMATE PRESSURE CAPABILITY

The ultimate pressure capacity of the D.H. depends on the strength characteristics of both flange and shell.

At ambient temperature, the critical location based on the assumed failure criterion is at the ellipsoidal to the cylindrical shell connection, with an ultimate pressure of 19.2 Kg/cm^2 and max radial displacement of about 3 cm.

At higher temperatures following main effects are detected: larger radial thermal expansion, reduced flange gap openings, additional bending stresses on the shell to flange junction, yeld limit stress reductions of both shell and materials, larger shell and bolt portions with material plastic behaviour. For the worst case, leading to inside surface shell max temperature of about 190 °C and to max bolt temperature of about 100 °C, the ultimate pressure decreases to about 14.4 Kg/cm^2.

7. LEAKAGE CHARACTERISTICS

The D.H.leakage potential depends on both flange sealing surfaces relative position and gasket material performance.

The calculated vertical relative displacements at the flange inside surfaces for various pressure and thermal loads are presented in fig.3.

Depending on specific thermal conditions initial flange separation begins between 4 and 6 Kg/cm^2, it increases almost linearly up to about 13 Kg/cm^2, reaching a value of 1.6 mm at ambient temperature, and finally it increases non linearly at higher pressures due to shell and bolts plasticizations.

The results obtained are in good qualitative agreement with test results of Ref. /3/. Temperature plays a role opposite to pressure. Flange separation decreases from inside to outside surfaces and the outside edges are always in contact.

The gasket material performance is highly dependent on its actual temperature. For silicone gasket types minimum degradation temperatures in a steam environment of about 250 °C are typically indicated, and they are lower than those expected under assumed severe accident conditions. Despite the relatively small computed flange separations, appreciable leak area would be found due to the large penetration diameter, if no sealing gasket effect is assumed.

8. REFERENCES

(1) Gou P.F. et al. "Containment Design of a Simplified Boiling Water Reactor (SBWR) Plant" 11th SMIRT 1991, H09/2.

(2) Olivieri M. et al. "SBWR - RCCV Top Slab Design by Analysis" 11th SMIRT 1991, H12/3.

(3) Hirao K. et al. "Pressure Test of the Typical Vessel Flange under Pressure Loading" 11th SMIRT 1991, J02/4.

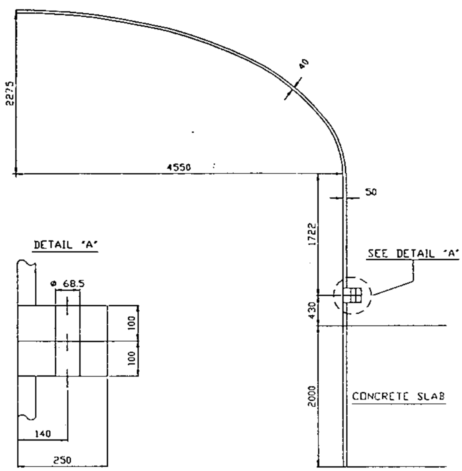

Fig.1 - DRYWELL HEAD CONFIGURATION

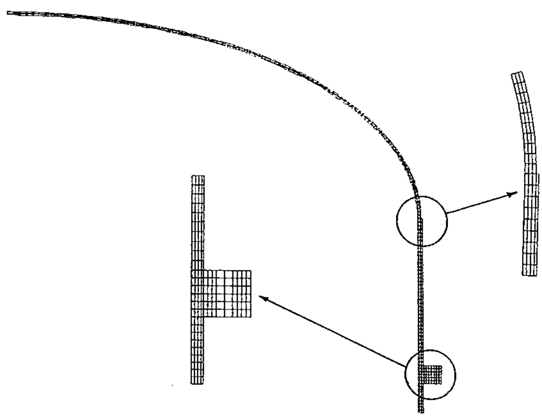

Fig.2 - DRYWELL HEAD FEM MODEL

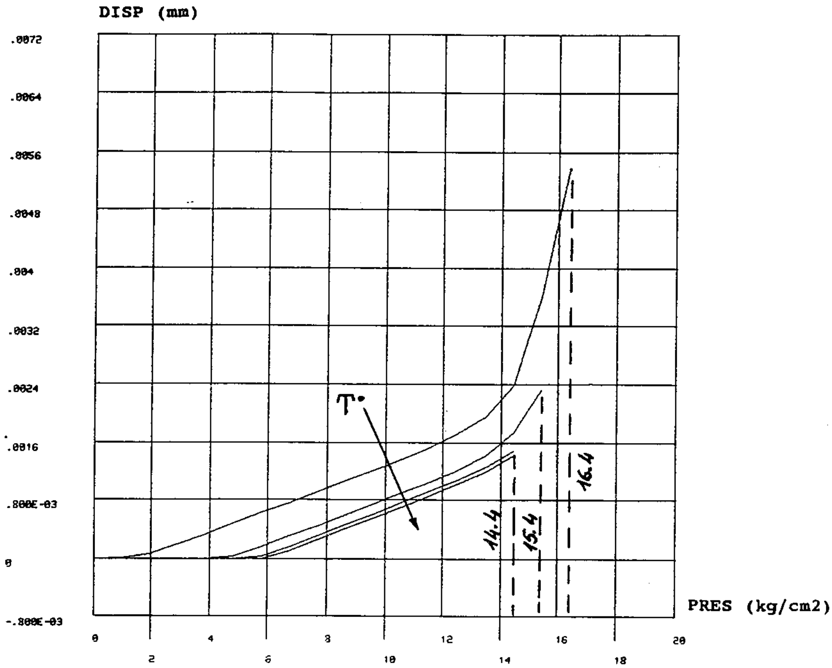

Fig.3 - FLANGE VERTICAL RELATIVE DISPLACEMENTS
AT INSIDE SURFACES