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SBWR - RCCV Top Slab Design by Analysis

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1 INTRODUCTION

In comparison with previous Mark III or ABWR designs, the SBWR Reinforced Concrete Containment Vessel (RCCV) Top Slab configurations proposed for feasibility and optimization studies are characterized with larger spans, possibly higher design pressure and presence of big openings for the isolation condensers; they constitute therefore a challenging structural design effort. The paper presents main results of the design and analysis activities, performed by Ansaldo within the SBWR Design Team framework, for the RCCV and more specifically for the Top Slab structures.

2 STRUCTURAL LAYOUT

RCCV and Top Slab (i.e. Upper Drywell Roof) configurations, typically proposed and here explicitly analyzed, are shown in figures 1 and 2.

The Top Slab extends beyond the junction with the lower cylindrical Containment up to the Safety Envelope (the square shaped intermediate walls of fig. 2) and constitutes a rather complex structural member due to its openings and its structural integration with the upper operating floor through the two heavy fuel pool floor girders, connected at the ends with the Safety Envelope, and other internal walls. All these walls limit the Isolation Condensers, Fuel Transfer, Drywell Head and Steam Separators Pools for an estimated total water volume of about 5800 m^3.

The Top Slab has a variable thickness of 2.00 and 2.20 m inside and outside the floor girders and 1.6 m from the junction with the Containment up to the Safety Envelope.

The analyzed configuration presents four circular openings (ϕ =3.2 m) for the Isolation Condensers and one opening (ϕ =9.4 m) for the Drywell Head; as the Top Slab represents a part of the SBWR Containment boundary, the lower surface is lined with a 8 mm thick stainless steel liner; portions of the upper surface, bottom boundaries of various supported pools, are steel lined also.

3 FEM MODEL AND ANALYSIS METHOD

The Top Slab structural behaviour was investigated with a 3D

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comprehensive FEM model of about 15000 DOF, by reproducing all main structural members and interactions with adjacent structures.

For such purpose a substructure approach (ref./1/) was adopted with two substructures consisting of the lower cylindrical RCCV portion and the upper Top Slab including pool girders, which are simply connected along the circumference of the RCCV wall. Interactions with exterior R.B. structures at selected elevations were also described with equivalent members and forces for pressure and seismic loads. Plate and shell elements with out of plane shear capabilities and with equivalent section properties for steel-concrete composite structural members (e.g. the Vent wall) were used. The Top Slab upper substructure model and the mesh refinement around the I.C. openings are shown in figures 3 and 4.

4 LOADING CONDITIONS

Main loads and load combinations for feasibility and preliminary design of the Top Slab were imposed to the structural model.

Main loads included dead and live loads, pool hydrostatic effects, seismic and LOCA loads. Seismic loads were specified as inertia forces of structural equipment and pool water masses, related to acceleration profiles, derived from a preliminary seismic analysis of the SBWR Nuclear Island (Ref. /2/), by including R/B interaction forces.

LOCA loads included differential pressures, wall thermal gradients and wall-heated liner interaction effects.

Different times spanning between few seconds and several hours after assumed LOCA were explicitly addressed to cover more significant phases of pressure loads (pool swell, flow peak, wetwell and drywell max differential pressures and max pressures), thermal loads (normal operating, max surface temperatures, max wall thermal gradients associated with long-term quasi linear through thickness temperature distributions) and equivalent pressure wall interaction loads caused by anticipated liner heating.

Thermal gradients were evaluated with a set of monodirectional thermal transient analyses for more significant structural locations and finally reduced to take into account postulated concrete cracking.

Both Service (Test) and Factored (Abnormal and Abnormal/Extreme environmental) conditions were considered to develop a preliminary set of load combinations, in accordance with the prescription of the reference ASME III Div. 2 Code, originating 158 detailed combinations, to include different possible combinations of the horizontal and vertical components, of the seismic excitation.

5 ANALYSIS RESULTS

The Top Slab static analysis showed that higher stresses (listed in table 1) are induced by pressure and thermal loads.

5.1 Pressure effects

The Top Slab behaves as a square stiffened slab (with the pool girders and separating walls), restrained at the junction with the lower cylindrical containment wall, exposed to upward acting pressure inside the containment boundary.

Max combined shear (195 t/m^2) and tension stresses (80 and 435 t/m^2 of membrane and bending respectively) occur on the bottom face at the junction with the containment. Local stress concentrations for the membrane tensile (about 200 t/m^2) and shear stresses (270 t/m^2) are found at the I.C. openings. Small effects are detected outside the containment boundary (not directly exposed to pressure) or inside the square portion of the slab constrained by the pool girders and partition walls, where membrane compression exists.

As an example the global magnified deformed shape of the top slab under the design internal pressure is shown in fig. 5, whereas membrane and bending longitudinal stress and shear stress distributions at the pool girder/top slab junction are presented in fig. 6.

5.2 Thermal effects

For more significant long term after LOCA thermal conditions, the Top Slab portion within the containment boundary undergoes a mean temperature (120°C) higher than the containment wall (89°C), due to the assumed heating of the upper I.C. pools, with a higher temperature on the bottom surface (138°C), whereas the opposite occurs for the Top Slab portion outside the Containment. Therefore even if, significant thermal bending stresses are found (327 t/m^2), their importance is reduced for the inner portion of the Top Slab because they cause compression on the bottom surface (opposite to the pressure effect) and are associated with membrane compressive stresses.

On the outer portion of the Top Slab, instead, thermal stresses play a significant role, as they would be characterized with membrane tension (646.7 t/m^2) and bending (937 t/m^2) with tension on the lower surface. Such preliminary values are conservatively based on a halved modulus of elasticity, but can be reduced to acceptable levels with a refined local analysis taking into account thermal stress relaxation as a result of concrete cracking.

5.3 Other effects

Among other effects, hot liner interaction loads are shown to produce significant effects on the inner portion of the Top Slab and additive with the LOCA pressure effects, with local concentrations around the Drywell Head opening mainly, due to the local actions exerted by the thick steel lower portion of the Drywell Head anchored in the concrete slab, and around the I.C. openings.

For sensitivity purposes an additional analysis with I.C. diameter typically increased by 15% was performed. The results indicate that increases of max stresses were generally small (7% maximum).

6 TOP SLAB FEASIBILITY

From the above discussed results and load combinations, a rebar layout satisfying requirements of ASME Section III Div. 2 Code was developed as shown in fig. 7. Construction feasibility and prefabrication procedures were investigated.

Significant but still reasonable quantities of reinforcing steel bars are required; the proposed rebar arrangement, shown in fig, 7, for the inner circular portion of the Top Slab results a combination of circumferential and rectangular patterns. Two orthogonal layers of rebars (ø36 mm at 15 cm) on top and bottom surfaces are generally used, with a third layer provided along the weaker direction orthogonal to the pool girders, on the bottom surface, due to the governing effect of the bending component.

One layer top and bottom of four circumferential bars (ø 36mm at 15 cm) is provided around I.C. and Drywell Head openings to withstand stress concentrations and around the Containment junction, to assure continuity with the cylindrical rebar pattern of the containment wall.

Transverse shear is carried in general with distributed orthogonal shear reinforcements (ø 16 mm at 15x30 cm) with increments in stress concentration areas such as around openings (ø 18 at 15x15 cm) and along the containment junction (ø 22 mm at 15x30 cm).

The assumed concrete thicknesses were found appropriate. A prefabricated assembly consisting of bottom liner, reinforcing rebars and construction support system, upper wall dowels, embedments for Drywell Head, upper liner, I.C. weights about 700 tons. Construction applying prefabrication that can result considerable time saving was assured.

7 CONCLUSION

A reinforced concrete Top Slab solution with a not uniform thickness and a reasonable reinforcing steel density to resist the computed combined stresses is feasible for the considered reference configuration. Local additional reinforcements are required in stress concentration regions such as penetrations and a significant amount of shear reinforcement is needed particularly at the containment junction. Further analyses are in progress, to investigate the ultimate strength of the analyzed configuration for PRA studies and to investigate optimized configurations.

8 REFERENCE

/1/ "COBRA 87: Modulo di analisi statica"
STUOASTO011, March 1988.

/2/ Olivieri, M.E. Traversone, G. Viti, "SBWR - Nuclear Island Parametric Seismic Analysis", 11th SMIRT 1991

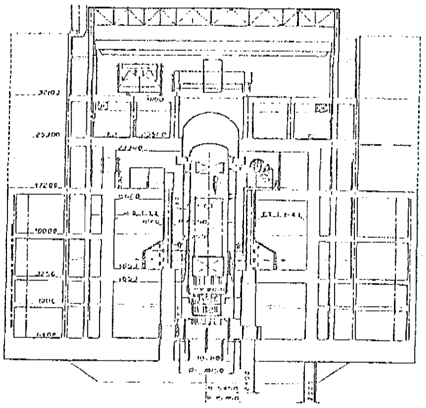

FIG.1 SBWR SECTION LAYOUT

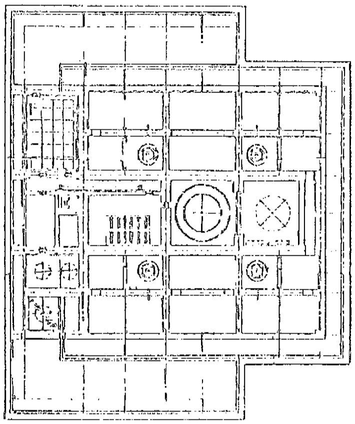

FIG.2 REFUELING PLAN

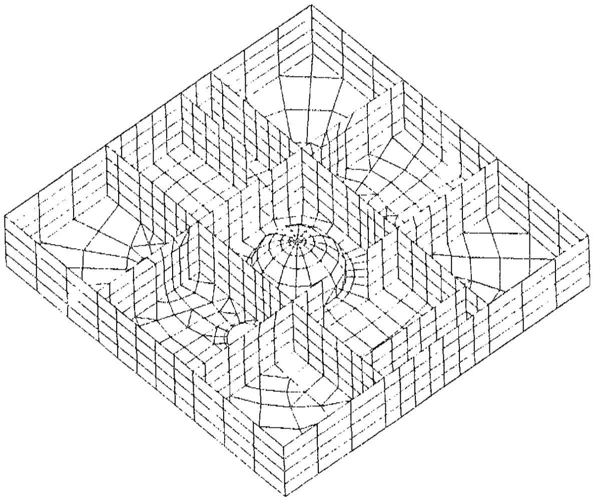

FIG.3 UPPER SUBSTRUCTURE FEM MODEL

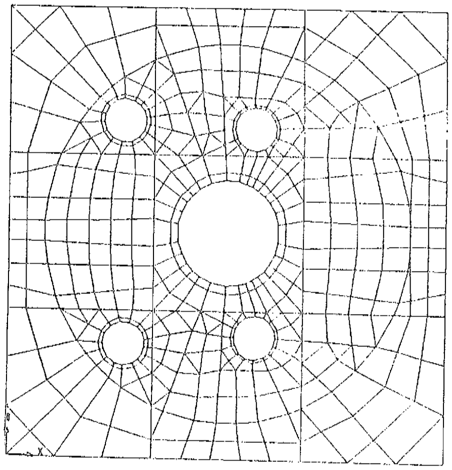

FIG.4 TOP SLAB FEM MODEL

LOAD	STRESS COMPONENT (t/m^2)	INSIDE CONTAINMENT			OUTSIDE CONTAINMENT
		TOP SLAB/ POOL GIRDER	I.C. HOLES	DRYWELL HEAD HOLE	TOP SLAB/ POOL GIRDER
D	membrane	70	70	52	-8
	bending	113	99	74	0
	shear	95.17	161.1	22.85	113.6
P_a	membrane	80	198.4	49.02	10
	bending	435	293	-248	94
	shear	195	269.4	182.6	100
T_a	membrane	-150	-80	-144	646.7
	bending	0	-111.6	-186	937
	shear	124.3	269.4	117.9	160

NOTE - POSITIVE BENDING: TENSION IN BOTTOM SURFACE
- Pa: design pressure
- Ta: post LOCA long term thermal loads

TAB.1 MAX STRESSES SUMMARY

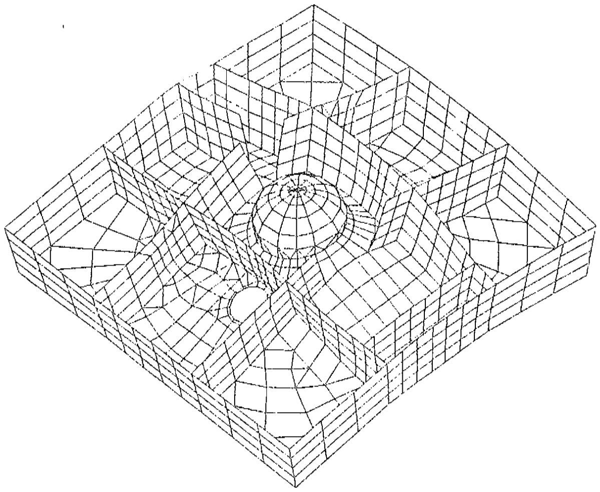

FIG.5 UPPER SUBSTRUCTURE DEFORMED SHAPE

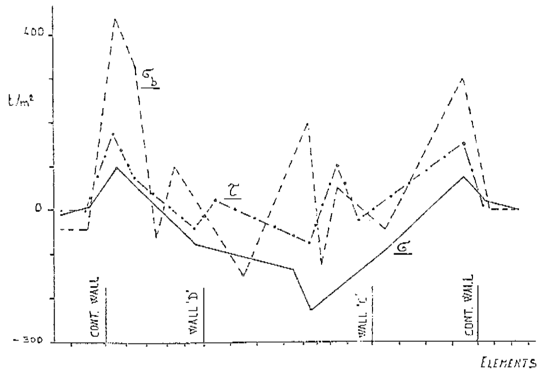

FIG.6 STRESSES AT TOP SLAB-POOL GIRDER JUNCTION

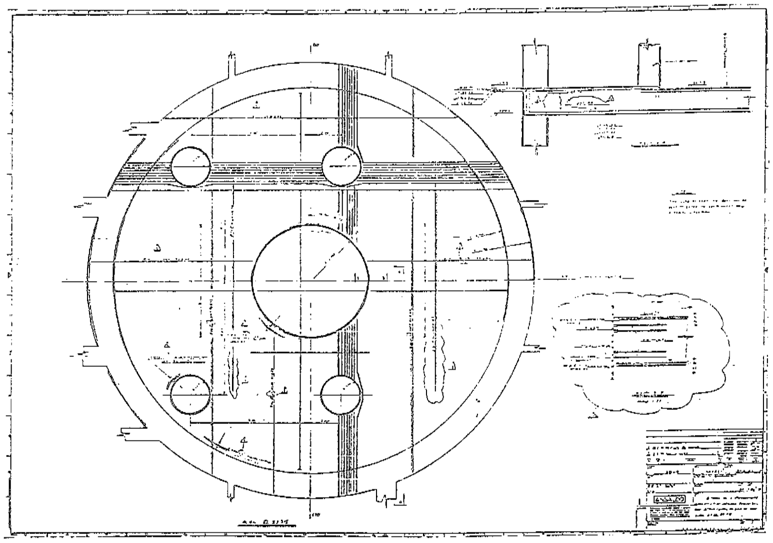

FIG.7 TOP SLAB REBAR ARRANGEMENT