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VVER-440/V213 bubbler condenser strength evaluation for design base LOCA conditions

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ABSTRACT: The bubbler condenser of the containment in a VVER-440/V213 type unit is the most important pressure suppression system. Stress calculations have been performed to asses the structural performance of the condenser for the loads acting after LBLOCA. Both hand calculation and a finite element modelling have been applied for the as built structure of NPP Paks. Some critical points of the structure have been identified. A comprehensive program is established for complex investigations of the bubbler condenser.

INTRODUCTION

The VVER-440/V213 reinforced concrete containment is a set of interconnected and sealed box-like compartments designed to withstand internal absolute pressure of 0.25 MPa. This is a peak value which may occur after a loss of coolant accident (LOCA), since the internal pressure is suppressed by a bubbler condenser. The condenser is placed in a 40 m wide, 32 m deep, and 40 m high tower connected to the steam generator compartment. The tower is separated in two sections; the condenser and the four section of the air trap part are connected through one way valves. The bubbler condenser trays are distributed on 12 levels and supported by 216 steel I-beams properly anchored into the tower walls. The tray are divided into six sections and filled with water with total volume of 1500 m^3. The water layer is of 0.5 m thick. The principal sketch of the condenser is shown in Figure 1. The condenser trays are made from 3 mm thick stainless steel sheets, stiffened by strip, L- and U-shape ribs. After a LOCA the air-steam mixture flowing from the steam generator compartment increases the pressure in the bubbler condenser tower. The increasing pressure will push the air-steam mixture through the water layer. The steam will condense in the pool and the non-condensable gases will pass to the air trap after the increasing pressure will open the one-way valves. During this process the structure of the bubbler condenser shall sustain the instantaneous pressure loads.

The thermohydraulic calculation of the post LOCA processes in the containment have been performed for the design base case as well as for the cases assuming reduced condensing capacity of the bubbler condenser which may increase of the maximum pressure up to 0.395 MPa. Although the thermohydraulical and mechanical performance of the bubbler condenser is essential for the VVER-440/V213 safety, the thermohydraulic and structural behaviour of the bubbler condenser under different LOCA condition is not well known.

There are different methodological studies sponsored by the IAEA for the evaluation of the bubbler condenser mechanical performance [1]. A PHARE project is launched for the investigation of the thermohydraulic processes in the condenser. These studies and projects reflect the great importance of the problem of bubbler condenser performance.

The objective of this work was to investigate the structural behaviour of the bubbler condenser for the loads acting after large break loss of coolant accident (LBLOCA) taken from plant documentation. Based on the stress evaluation the critical structural parts have been identified and a program of further investigation has been started.

LOADS AND LOAD COMBINATIONS

The instantaneous pressure difference between the bubbler condenser tower vertical shaft and the condenser tray enclosure is acting on the bubbler condenser steel walls after a LOCA. The time history of the pressure difference could be calculated, but the different thermohydraulic calculations give rather scattering values. The pressure drop maximum may occur after 5 s from the beginning of the process and after 15 s the pressure difference diminishes.

The real design value of the pressure drop between inside and outside area of the condenser is not known. From different sources a maximum pressure difference of 30 kPa can be identified. This value of the pressure difference is frozen, the calculation is static. The short time feature of the load is taken into account in the definition of the allowable stress values.

The load combination consists of dead load, hydrostatic load of the 0.5 m thick water layer and the pressure difference mentioned above.

The bubbler condenser is not included into the list of systems relevant for seismic safety and the coincidence of the Safe Shutdown Earthquake and a LOCA could be neglected. A combination of the Design Base Earthquake and LOCA loads will be evaluated in the latter phase of the project.

MATERIAL PROPERTIES AND ALLOWABLE STRESSES

The bubbler condenser trays are made from stainless steel plates of 3 mm thickness of type 12H18N10T. The supporting I-beams are made from steel VSZT3 (36.24).

The material properties and allowable stresses have been taken from the Russian code PNAE-G-7-002-86.

Parameters at 100 C°	stainless steel 12H18N10T	steel VSZT3 (36.24)
R^T_m ultimate tensile stress [MPa]	456	353
$R^T_{p0.2}$ yield stress [MPa]	186	235
allowable strain [%]	33	22
allowable contraction [%]	40	49
Young modulus[MPa]	200	200
allowable for reduced overall membrane stress [MPa]	$(\sigma)_1 \leq 1.4[\sigma]=173.6$	$(\sigma)_1 \leq 1.4[\sigma]=135.8$
allowable for local membrane plus overall bending stresses [MPa]	$(\sigma)_2 \leq 1.8[\sigma]=223.2$	$(\sigma)_2 \leq 1.4[\sigma]=244.4$

$[\sigma]=\min[R^T_{p0.2}/1.5, R^T_m/2.6]$

HAND CALCULATIONS

In the first phase a hand calculation of the stresses was performed taking into account the as built conditions of the NPP Paks. The evaluation was performed separately for all essential load bearing elements of the condenser (I-beam supports, tray bottom sheet, stiffening ribs, U-shape caps, tray inside, face and end wall sheet, cover sheet, etc.).

The size of the areas between the reinforcing ribs allows to evaluate the stresses as for a uniform loaded thin plate. The ribs could be evaluated also separately together with the adjoin part of the sheet according to Soviet code SNiP II-B.3.62. valid at the time of the design of the VVER-440/V213 bubbler condenser design or the Hungarian code MSZ 15024/1-85. First the calculation has been used the linear elastic theory. As a second step the large deformations have been taken into account too, because the deformation of the plates are greater then the half thickness (see, e.g. [2]). The results are summarised in the Table below.

	LOAD	LINEAR EL. STRESS MPa	LARGE DEF. STRESS MPa	COMMENTS
bottom plate sheet	$\Delta p+p_{hs}=0.025$	462	223.2	stress check OK
bottom plate sheet stiffening ribs	$\Delta p+p_{hs}=0.025$	223.2 bending 43.4 shear $(\sigma^2+4\tau^2)^{1/2}<1.1(\sigma)_2$ $219.0=<1.1(\sigma)_2$		stress check OK stability OK according [3]
inside wall sheet	Δp only, since the hydrostatic load is negligible	22.9		stress check OK
∩-cap sheet	Δp, overestimated, in fact the pressure is varying along the height of the sheet	611.	173.6	if the ribs can withstand the load
∩-cap stiffening ribs	coming from the overestimated cap sheet load	4469.6		stiffening required
cover plate sheet	Δp	683	296.3	stiffening required
cover plate sheet U ribs	Δp	323.0		stiffening required
face wall sheet	Δp only, since the hydrostatic load is negligible	60.17		stress check OK
face wall sheet ribs	Δp only, since the hydrostatic load is negligible	349.1		OK, if the cross-ribs will be stiffened
end wall sheet	Δp only, since the hydrostatic load is negligible	486		stiffening required
end wall sheet ribs	Δp only, since the hydrostatic load is negligible	351.9		stiffening required

The I-beams supporting the trays are of specific interest. The I-beam has a web that is of 560 mm high and 11.1 mm thick and the flanges are 190 mm wide and 17.8 mm thick. the length of the beams is 8550 mm. The 6750 mm wide condenser trays are placed asymmetric on the beams. The distance between the internal vertical wall of the condenser shaft and the condenser is equal to 550 mm. There are four different significant load cases, at different positions of the I-beams:

Case No.1: It is the position at the middle of the shaft where the deformation of the vertical reinforced concrete wall is largest, this deformation causes an in plane normal force for the beams. The pressure difference in and outside of the trays does not affect the beam, because the load from pressure difference acting on the bottom plate of the tray above the beam and the load from pressure difference acting on the cover of the tray below of the beam are compensating each other. The beams in this position bear the weight of the structure and of the water in tray.
In this case the I-beam can bear the loads: σ=160.3 MPa $<(\sigma)_2$

Case No.2: It is the position at the middle-height of the shaft wall and at the edge of the tray. In this position among the loads defined above a distributed load perpendicular to the plane of the beam exits due to the pressure difference acting on the end wall of the trays. This load cause bending of the beam. The load from the weight of the structure is smaller than in the case before.
In this case the I-beam can not bear the loads: σ=2536 MPa $>(\sigma)_2$

Case No 3: It is the position of the I-beams at the lowest elevation and not on the edge position. The load from the supported structure is a little smaller as above, but the load due to pressure difference acting on the bottom sheet of the first tray is not compensated. The load due to the deformation of the shaft wall is negligible.
The beam can bear the loads: σ=108.1 MPa $<(\sigma)_2$

Case No 4: It is the position of the I-beams at the lowest elevation and at the edge position. The loads are the same as in the case No 3, but a distributed load perpendicular to the plane of the beam exits due to the pressure difference acting on the end wall of the tray above the beam. This load causes a torsion of the beam.
The beam can not bear the loads: σ=1268 MPa $>(\sigma)_2$

The most critical point seems to be the strengthening of the I-beams at the edge positions using beam supports connecting the flanges of the beams to the tower walls. The supports shall be applied to the lower flange in the case of most upper edge beams, to the upper flange in case of lowest edge beams, and to the upper and lower flanges in the case of all other edge beams.

FINITE ELEMENT CALCULATION

The modelling

Adequate finite element models were elaborated for seven different parts of the condenser. The models composed from beam and thin rectangular shell elements. Fine mesh is applied on the critical areas identified by the hand calculations. The different parts of the tray could be modelled separately. Selecting the model size the symmetry of the tray has been considered.

The edge section, the next to edge section and the half of the middle section of the condenser tray has been included into the models. The following models have been analysed:

- tray bottom plate and the inside wall (sheet with ribs)
- -cap (sheet with ribs)
- cover plate (sheet with ribs)
- face wall (sheet with ribs)
- end wall (sheet with ribs).

Two types (sizes) of the face and end walls have been considered because the height of the condenser tray at the most upper level is greater)

The evaluation results

The calculation was performed assuming linear elastic behaviour and small deformations. The membrane and the membrane+bending stresses are obtained and evaluated. The results are in good correspondence with those obtained in hand calculation. The finding can be summarised for each condenser component as follows:

- The tray bottom plate membrane and membrane+bending stresses are globally below allowable values, only those areas are locally overstressed where the ribs of the vertical walls are joining to the bottom plate sheet. These rib joints can be stiffened easily.

- The weakest component of the condenser is the ∩-cap. Critical are equally the cap top and side sheets and especially the ribs stiffening the side sheets and fixing them to the tray bottom plate. The welding of the rib to the bottom plate is 10-13 times overloaded relative to the allowable stresses. The cap top sheet is overstressed 8-10 times. The deformed shape of the cap structure and the membrane+bending stress distribution is shown in Figure 2. Although the loss of the structural integrity is inescapable, the loss of functionality is not obvious because the flow path for the air-steam mixture may be not blocked, only the shape of the channel leading the mixture through the water layer will be deformed. In spite of this the ∩-cap has to be strengthen.

- The cover plate of the condenser tray is overstressed (1.6-2.2 times). The cover can be stiffened easily by new ribs in the middle and at the edge of the of sheets.

- Both type of face walls (also the higher one) can withstand the loads.

- Both type of the end walls shall be stiffened. Stiffening strip may be applied at the edges of the sheets and new ribs may be added parallel with the old one in the middle of the sheets.

CONCLUSIONS

The calculations show there are critical components of the bubbler condenser which may fail under assumed 0.03 MPa pressure difference load. Considerations shall be made on strengthening of the condenser ∩-cap and the I-beams at the edge position, because the loss their structural integrity may cause loss of condenser functionality and subsequently an over-pressurisation of the containment after a LOCA. The problem identified is one of the most important safety issue of the VVER-440/V213 reactors.

For the solution of the problem the thermohydraulic behaviour of the condenser has to be investigated. A PHARE project is launched for the experimental and theoretical investigation of the thermohydraulic processes in the condenser. One of most important output of this work should be the pressure difference time history, i.e. the load which may act on the condenser structure. The final evaluation and decision on the upgrading measures will be made on the basis of experimentally verified loads.

REFERENCES

1. *Evaluation Guidelines for Bubbler Condenser Metallic Structure in WWER440/213 NPPs Containment*, IAEA Report, Vienna, Austria, 1994

2. Timoshenko S., Woinowsky-Krieger S.: *Theory of Plates and Shells*, McGraw-Hill, 1959

3. Timoshenko S.: *Stability of Elastic Systems*, (in Russian), Moscow, 1955

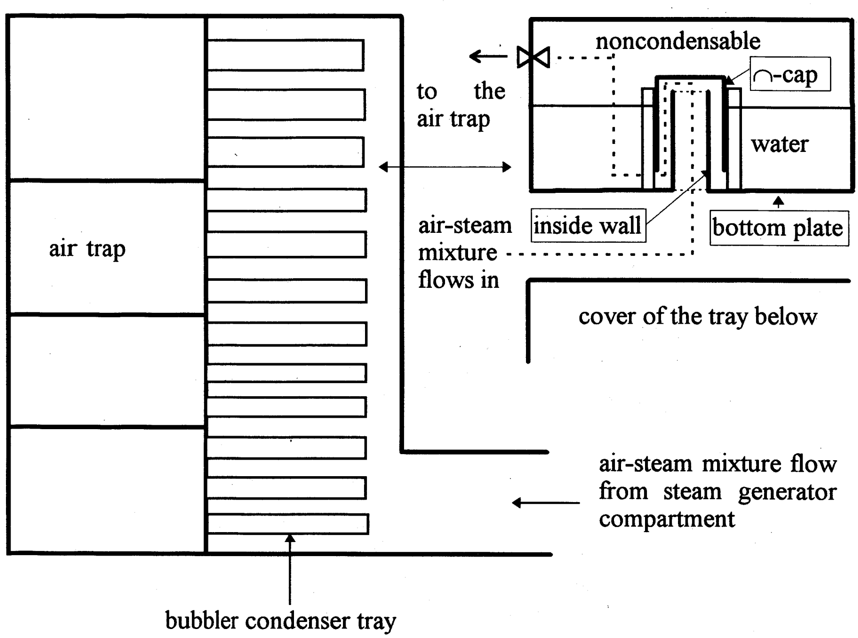

Fig. 1. Principal scheme of the bubbler condenser tower and the condenser tray.

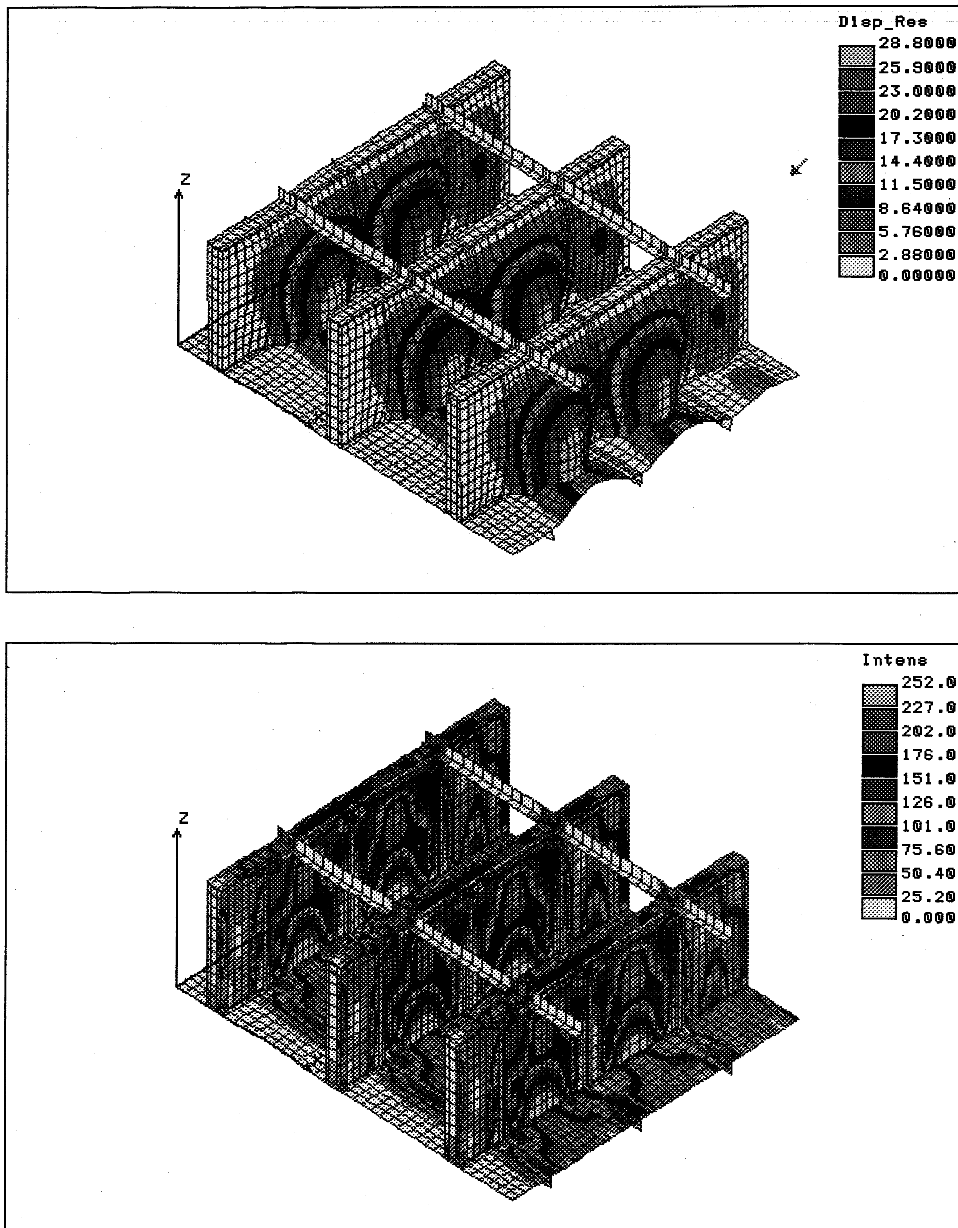

Fig. 2. Displacement and stress distribution in the condenser tray bottom plate and the ∩-cap