



## Analysis of the Bubble Condenser Structure of Wwer-440 Npp under Loca Loading

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### ABSTRACT

Analysis of the bubble condenser structure under LOCA loading is presented in this paper. There was a lot of computational work performed relating to this topic. The complex research of this problem was performed in the scope of PHARE 2. 13/95 project. The results of this project identified following possible problems:

1. Problem with the uplift of the beams I 600 of the first floor
2. Possible plastic collapse of the wall on the 12th floor

Taking into account fact that these possible problems were identified 7 years ago author decided to evaluate them using the latest computational method. The FEM model of the bubble condenser was created in the ANSYS 6.0 environment and analyzed for the pressure loading defined for the LOCA accident in IAEA TECDOC 803. This is the first complex model of the bubble condenser structure including all geometrical and material non-linearities. The duration of the pressure wave is 0.4 s with the amplitude of 30 kPa.

The results of performed analyses show us that the most critical failure mode is not a plastic collapse of the tank wall. Weld connections appear to be the most critical parts of whole structure.

**KEYWORDS:** Bubble condenser, plastic collapse, LOCA loading.

### INTRODUCTION

The problem of bubble condenser was analyzed in the scope of of PHARE 2. 13/95 project in the detail. The results of this project identified following possible problems:

1. Problem with the uplift of the beams I 600 of the first floor
2. Possible plastic collapse of the wall on the 12th floor

Taking into account fact that these possible problems were identified 7 years ago author decided to evaluate them using the latest computational method. Schematic sketch of the bubble condenser structure is shown in Figure 1.

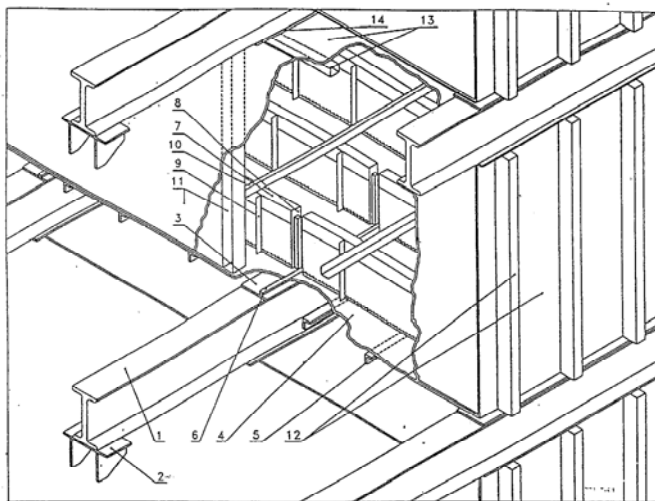


Figure 1 – Sketch of Bubble Condenser Structure

## LOADING FUNCTION

The loading pressure time history acting on the bubble condenser structure during the LOCA accident was developed based on IAEA Document [1]. There is introduced the summary of the analytical results and tests already performed. The conclusions are following:

1. The time for hydro-lock opening is equal to 0.2 – 0.4 s
2. The maximal pressure difference acting to the pressure barrier is equal to 12 – 35 kPa

The loading function used for the analysis is shown in Figure 2.

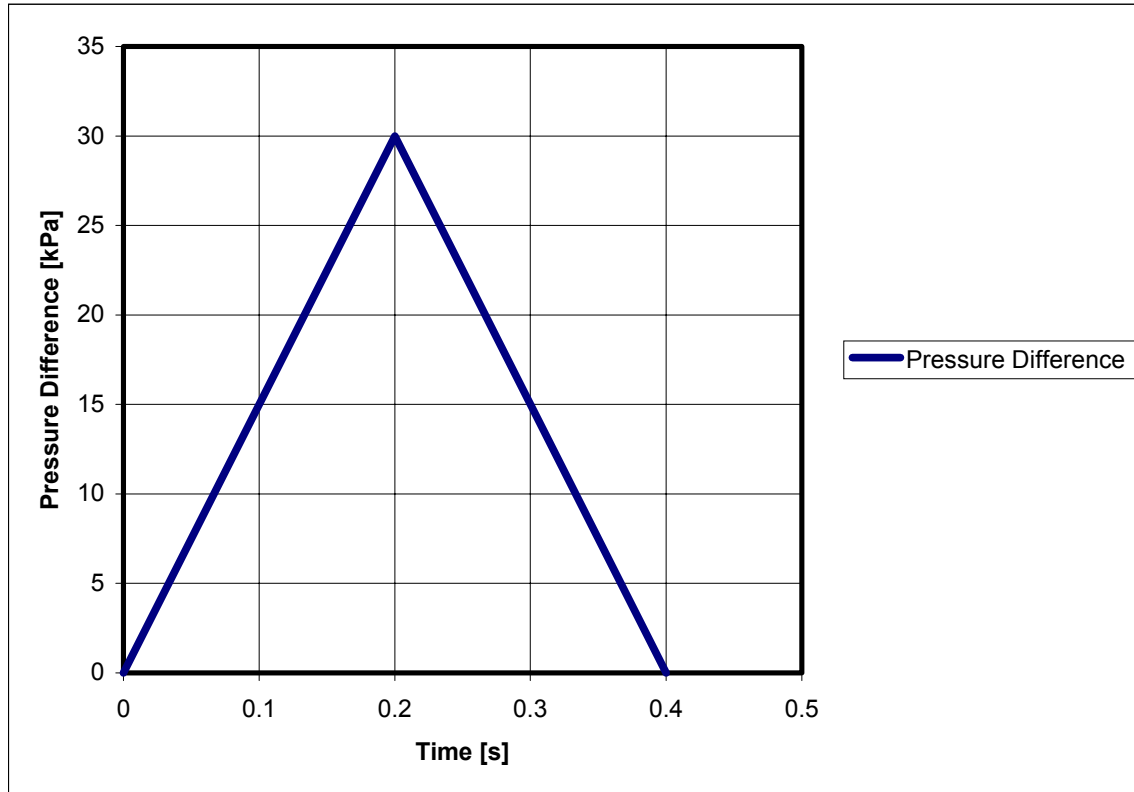


Figure 2 - Loading Function Used

## DESCRIPTION OF FEM MODEL

Behavior of the bubble condenser structure during LOCA accident was analyzed using FEM Code ANSYS 6.0 [2]. There were developed two FEM models of 1st and 12th floor. Whole model was created using shell and beam element types. The material was assumed as non-linear with material characteristics introduced in Figure 3. The theory of large deformation was used. The response was then obtained using explicit integration schema assuming inertia effects and rate dependent plasticity. The failure strain was defined equal to 0.3. Strain rate is accounted for using the Cowper-Symonds model which scales the yield stress by the strain rate dependent factor as shown below:

$$\sigma_Y = \left[ 1 + \left( \frac{\dot{\epsilon}}{C} \right)^{\frac{1}{P}} \right] (\sigma_0 + \beta E_p \epsilon_p^{eff}) \quad (1)$$

where

- $\sigma_Y$  - yield stress
- $E$  - Young modulus
- $\sigma_0$  - initial yield stress,
- $\dot{\epsilon}$  - strain rate

C and P - Cowper-Symonds strain rate parameters  
 $\epsilon_p^{eff}$  - effective plastic strain

$E_p$  is the plastic hardening modulus which is given by

$$E_p = \frac{E_{tan} E}{E - E_{tan}} \quad (2)$$

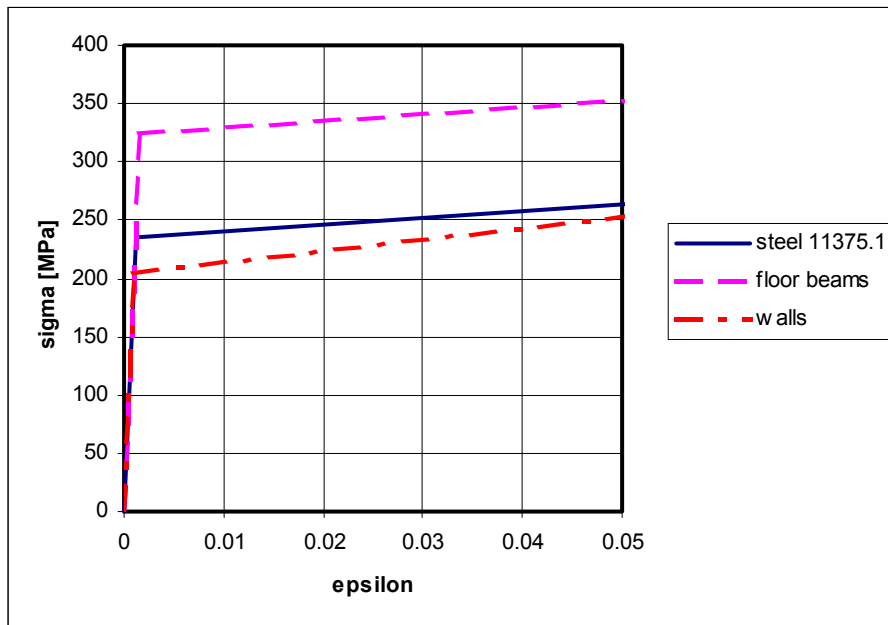


Figure 3 – Material Characteristics

The FEM models are shown in next Figures.

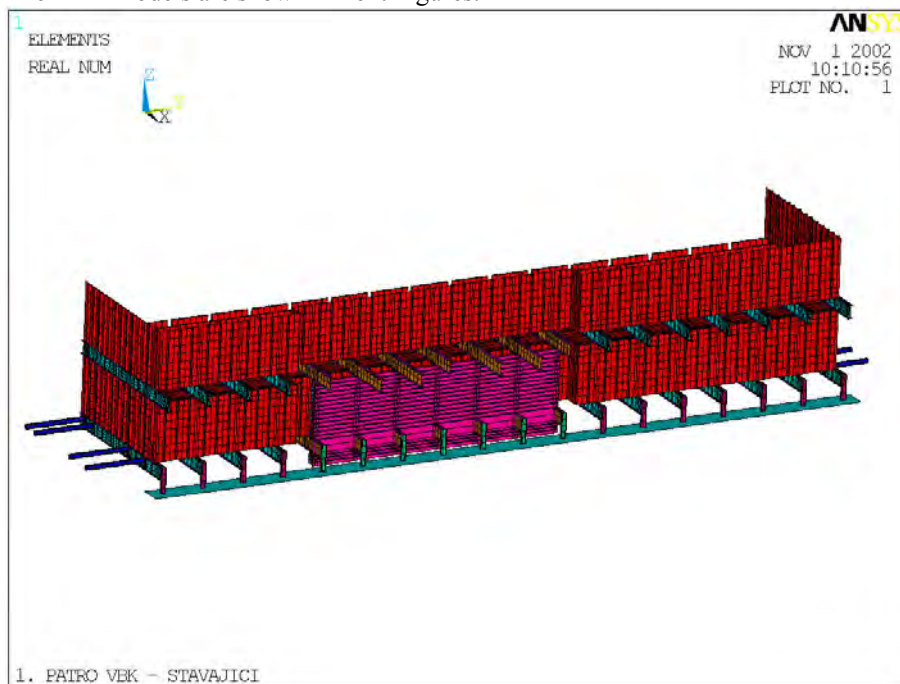
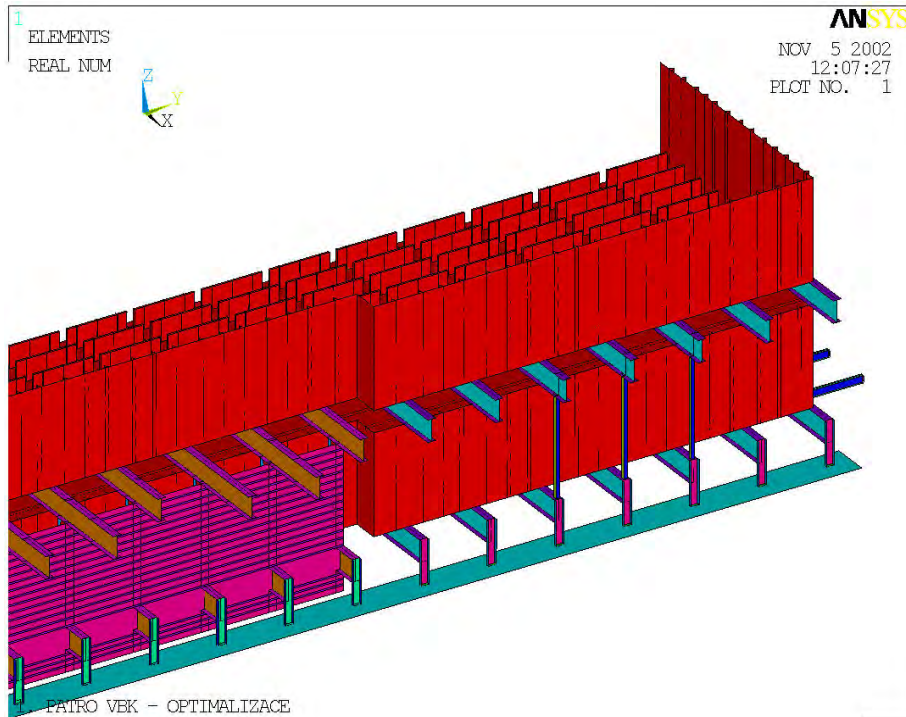
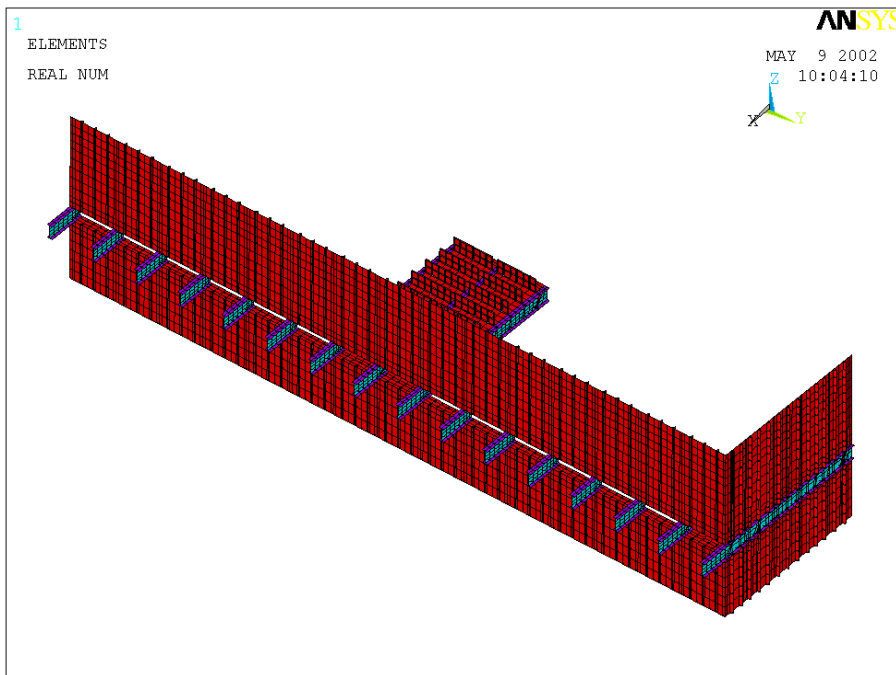


Figure 4 – Analytical Model of 1<sup>st</sup> Floor – As Built State



**Figure 5 – Analytical Model of 1<sup>st</sup> Floor – Upgraded State**



**Figure 6 – Analytical Model of 12th Floor**

## FAILURE MODES

There were chosen two dominant failure modes:

1. Plastic collapse of the walls
2. Rupture of connecting welds

## RESULTS OF ANALYSIS

The equivalent stress (SEQV) and displacement distributions are shown in next Figures. The units introduced in legends are SI units.

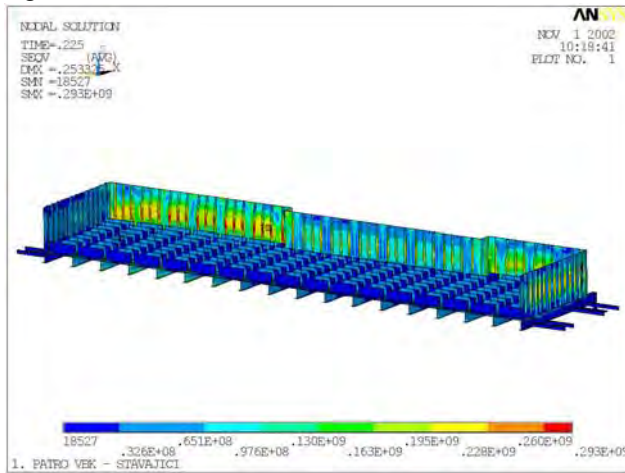


Figure 7 – 1st Floor SEQV – As Built State

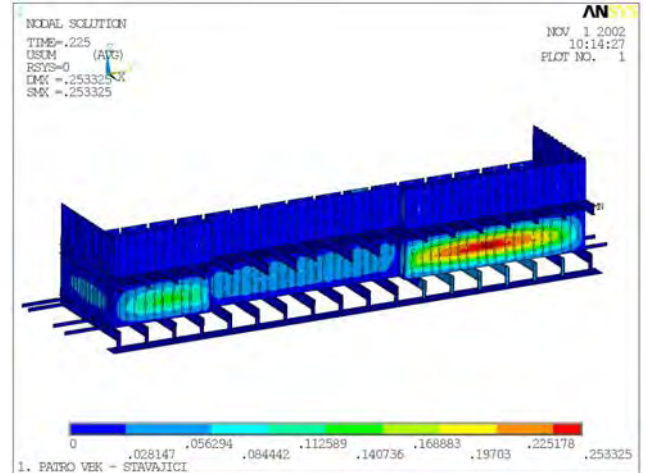


Figure 8 – 1st Floor Displacement Distribution – As Built State

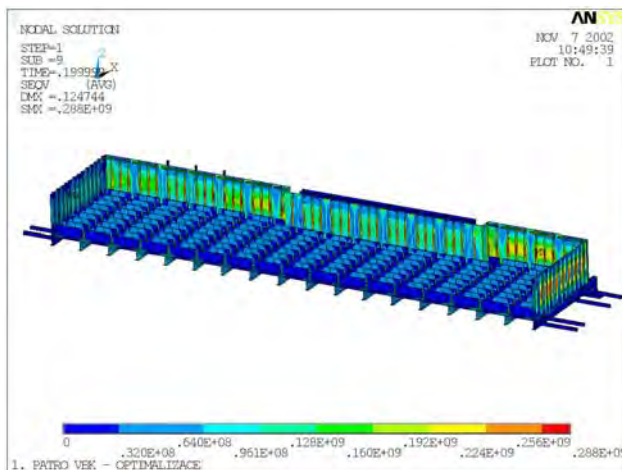


Figure 9 – 1st Floor SEQV – Upgraded State

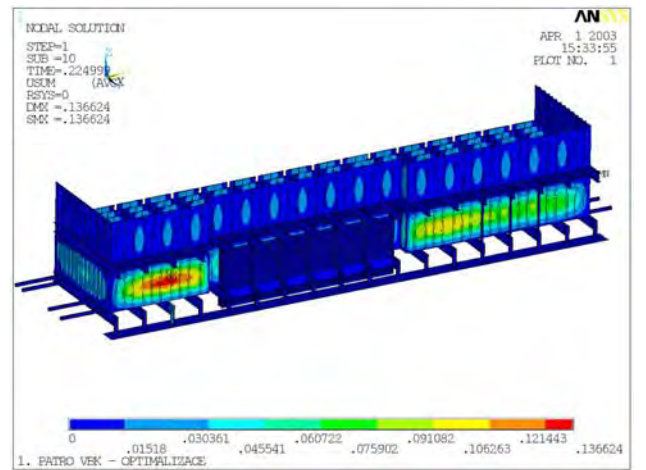


Figure 10 – 1st Floor Displacement Distribution – Upgraded State

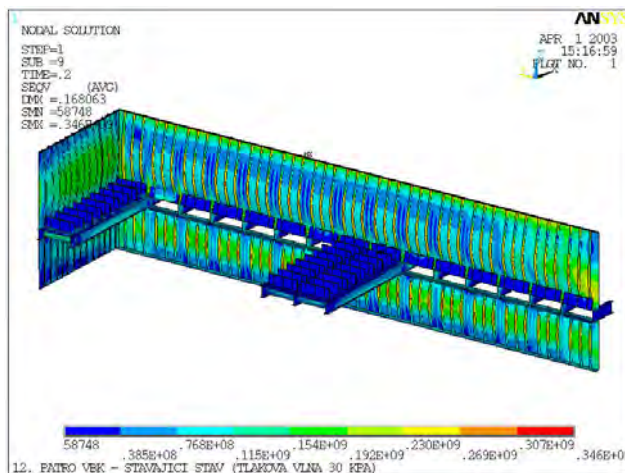


Figure 11 – 12th Floor SEQV

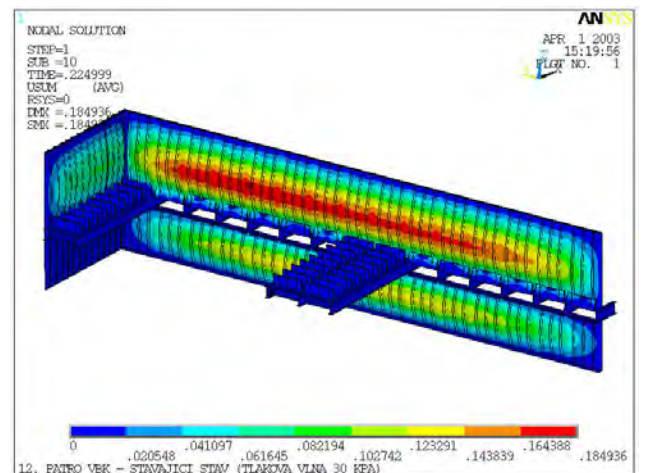


Figure 12 – 12th Floor Displacement Distribution

Taking the loading from FEM calculation the critical weld connections were then analyzed. The critical welds for both analyzed floors are identified in next Figures.

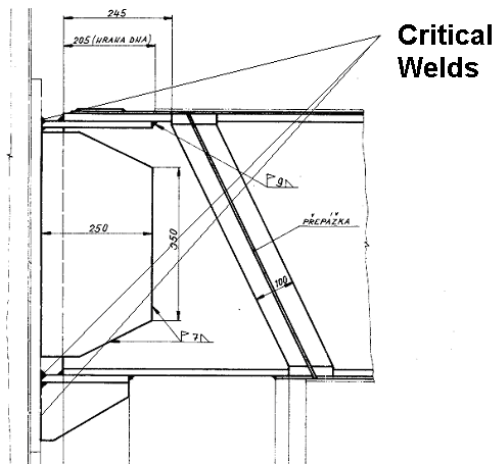


Figure 13 – Critical Weld – 1st Floor

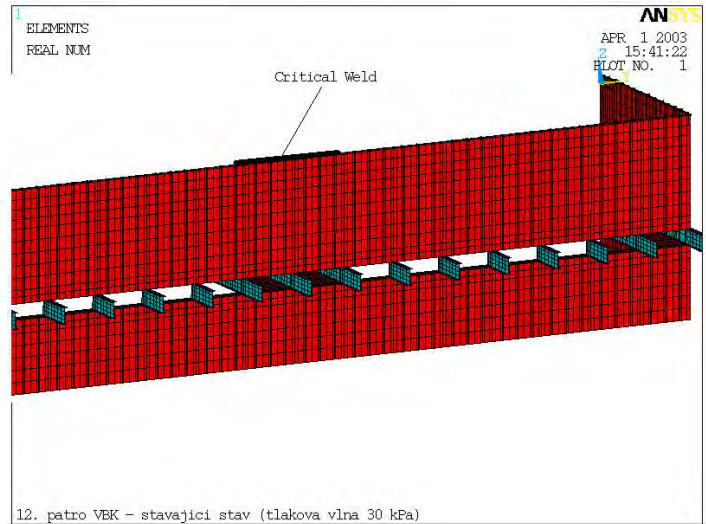


Figure 14 – Critical Weld – 12th Floor

General stresses in welds are then shown in next Figures

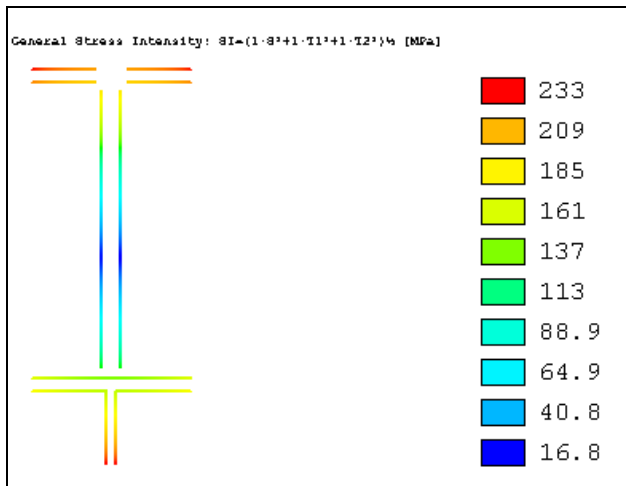


Figure 15 – Weld Stress – 1st Floor

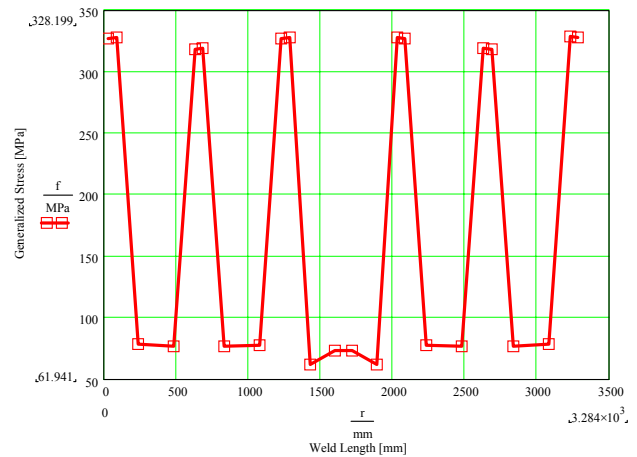


Figure 16 – Weld Stress – 12th Floor

Adopting limits introduced in ASME Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components, Division 1 [3] the value of allowable weld stress is equal to 200 MPa. Comparing this limit with the computed maxims we cannot verify weld connections in “as built state”. For this reason it was necessary to increase capacity of the welds. For the 1<sup>st</sup> floor it was done by installation of three reinforcing profiles between 1<sup>st</sup> and 2<sup>nd</sup> floor. This upgrading reduced bending of the floor beams and it also decreased the forces and moments acting to the critical weld connection. In the case of 12<sup>th</sup> floor there are several possibilities how to upgrade this critical wall-liner weld connection. In the case of Paks NPP it was solved by installation of the artificial roof and that way the pressure acting to the wall was reduced. Our company offers the different solution. We recommend installation of reinforcing ribs in the locations of peak weld stresses. This solution seems us to be less expensive in comparison with the solution applied in Paks NPP.

## CONCLUSION

Performed analysis showed that the critical failure mode for the bubble condenser under LOCA accident is not a plastic collapse of the tank walls but the critical parts are the weld connections. The tank walls are very ductile and the results of performed analyses are in compliance with the test simulating the LOCA accident. There was no damage of the tank walls during these tests.

## REFERENCES

- [1] Report of the IAEA Technical Co-operation Project RER/9/004 on Evaluation of Safety Aspects for WWER-440 model 213 nuclear power plants
- [2] ANSYS 6.0, User Manual, Theory Manual, Analysis Guide ANSYS Inc., Houston, USA.
- [3] ASME Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components, Division 1