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Probabilistic Nonlinear Analysis of Bubble Tower Structure due to Extreme Pressure and Temperature

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Abstract: This paper presents an application of the probabilistic analysis of structural resistance of the bubble tower structure of a VVER 440/213. The evaluation is based on an extension of the smeared crack model developed on basis of Kupfer's bidimensional failure criterion, rotated crack, CEB-FIP model of failure energy and implemented into the ANSYS system. The non-linear analysis was considered for the median values of the input data and the probabilistic analysis models the uncertainties of loads, material resistance and other modeling issues.

Introduction

The definition of the fragility curve for containment of a nuclear power plant (NPP) generally represents a crucial step for the level 2 probabilistic safety assessment (PSA L2), where the probability of containment failure can be evaluated as the convolution of the fragility curve with the load curve (SSG-4). The assessment of the structural strength of the containment of a nuclear power plant has acquired even a greater importance in the framework of post-Fukushima stress tests where the assessment of the safety margin and off-design conditions.

In the case of the loss-of-coolant accident (LOCA) the steam pressure expand from the reactor hall to the bubble condenser. Hence, the reactor hall and the bubble condenser are the critical structures of the NPP hermetic zone.

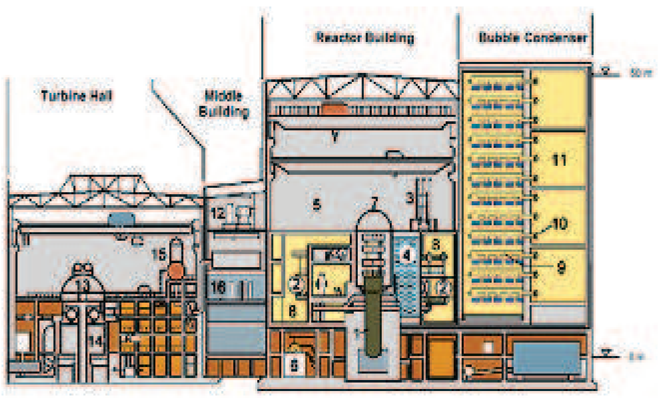

Fig. 1: Section plane of NPP VVER 440/213

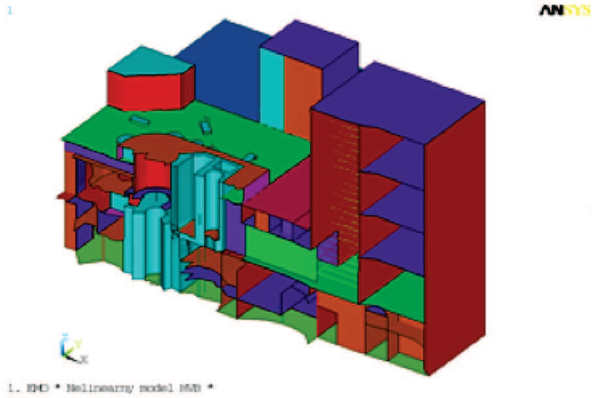

Fig. 2: Calculation FE model

The present work analyses the impact of combination of pressure load with thermal load that can arise in extreme situation related to severe accident progression. For the purpose, a detailed finite-element analysis of the concrete structure was carried out with ANSYS software and the program CRACK [1, 2] were provided to solve this task.

The theory of large strain and rate independent plasticity were proposed during the high overpressure loading using the SHELL181 layered shell element from the ANSYS library [1]. The layered approximation and the smeared crack model of the shell element are proposed. The processes of the concrete cracking and crushing are developed during the increasing of the load.

The limit of the finite element damage is controlled by the failure energy [3]. The program CRACK based on the presented nonlinear theory of the layered reinforced concrete shell was adopted in the software ANSYS [1, 2].

Evaluation of the fragility curve

The previous design analyses of the containment failure determine the critical area of this structure. The semi probabilistic methods were applied for the probabilistic analysis of the containment failure in this paper. The probabilities of the containment failure were considered in the critical structure areas on the basis of the nonlinear deterministic analysis of them for various levels of the overpressure. The probability of containment failure is calculated from the probability of the reliability function in the form

$$p_f = P\left(\frac{1}{t}\sum_{l=1}^{N_{lay}} F_u^l\left(I_{\varepsilon 1}; I_{\varepsilon 2}; \varepsilon_u\right) t_l > 0\right) \qquad (1)$$

where $F_u^l(.)$ is the Kupfer's failure function.

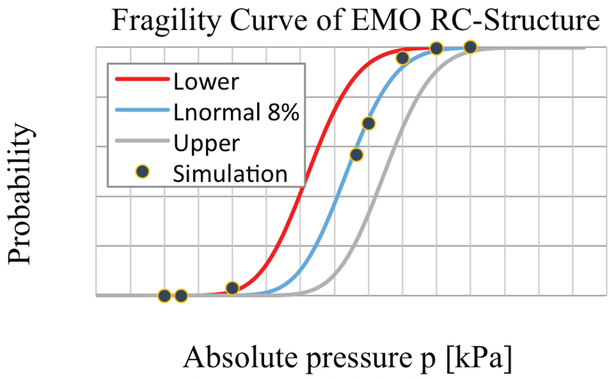

Fig. 3. Idealized fragility curves with boundary ±5%

Summary

The probability analysis of the loss of the concrete containment integrity was made for the overpressure loads from 250kPa to 500kPa using the nonlinear solution of the static equilibrium considering the geometric and material nonlinearities of the reinforced concrete shell layered elements. The uncertainties of the loads level (temperature, dead and live loads), the material model of the composite structure (concrete cracking and crushing, reinforcement), and liner and other influences following from the inaccuracy of the calculated model and the numerical methods were taken into account in the Monte Carlo simulations (Králik, 2009). The probability of the loss of the concrete containment integrity is less than 10^{-6} for the original structural model. The containment failure is equal to 0,050422906 for the overpressure 275,5 kPa.

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