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PROBABILISTIC ANALYSIS OF MACHINE TOOL STRUCTURES FRAGILITY ON EXTREME SNOW IMPACT

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Abstract: *This probabilistic assessment of NPP structures for Probabilistic Safety Analysis (PSA) level 2 of VVER 440/213 in the case of the extreme external even without the earthquake is presented. On the base of the meteorological monitoring of the locality, the extreme load parameters were defined for the return period 104 years using the Monte Carlo simulations. There is showed a summary of calculation models and calculation methods for the probability analysis of the structural resistance. The general purpose of the nonlinear probabilistic analysis of the NPP structure resistance was to define the safety level of the critical structural elements. The numerical simulations on the base of the LHS method were realised in the system ANSYS and FReET.*

Keywords: Probability, Nonlinearity, Fragility, Extreme snow, NPP, ANSYS, FReET.

1. Introduction

This paper deals with the resistance of the steel hale frame of the nuclear power plant (NPP) in the locality of Mochovce. The international organization IAEA in Vienna (IAEA, 2006) set up the design requirements for the safety and reliability of the NPP structures. The extreme environmental events (e.g. wind, temperature, snow, explosion...) (Kralik, 2009, 2019 and NUREG, 1992) are the important loads from the point of the NPP safety performance. The extreme loads are defined with the probability of mean return period equal to one per 10^4 years (IAEA, 2006 and Kralik, 2009, 2019).

Fig. 1: View to the machine tool structures of the NPP with reactor VVER440/213.

2. Probabilistic assessment

Most problems concerning the reliability of building structures are defined today as a comparison of two

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stochastic values, loading effects E and the resistance R, depending on the variable material and geometric characteristics of the structural element (Kralik, 2009, 2019, HANBOOK, 2005, JCSS, 2011, Krejsa, 2016)

$$RF = g(R, E) = R - E \geq 0 \tag{1}$$

where RF is the reliability function. In the case of the simulation methods, the failure probability is calculated from the evaluation of the statistical parameters and theoretical model of the probability distribution of the reliability function $RF = g(X)$. The failure probability is defined as the best estimation on the base of numerical simulations in the form

$$p_f = \frac{1}{N}\sum_{i=1}^{N} I\left[g(X_i) \leq 0\right] \tag{2}$$

where N is the number of simulations, $g(.)$ is the failure function, $I[.]$ is the function with value 1, if the condition in the square bracket is fulfilled, otherwise is equal 0.

3. Action effects on NPP structures

The IAEA requirement proposes to calculate the structure for situations - test conditions, design accident conditions, service conditions and the extreme environmental conditions. They are presented in the loading action due to the extreme snow.

The load combination of the deterministic and probabilistic calculation is considered according to IAEA and EN 1990 (HANDBOOK, 2005) for the ultimate limit state of the structure as follows:

➲ ***Deterministic method – extreme design situation***

$$E_d = \gamma_g G_k + \gamma_q Q_k + \gamma_a A_k \tag{3}$$

➲ ***Probabilistic method – extreme design situation***

$$E = G + Q + A_{Ex} = g_{var} G_k + q_{var} Q_k + a_{var} A_{Ex.k} \tag{4}$$

where G_k is the characteristic value of the permanent dead loads, Q_k - the characteristic value of the permanent live loads, A_k - the characteristic value of the extreme loads, γ_g, γ_q, γ_a are the loading parameters ($\gamma_g = \gamma_q = \gamma_a = 1$ for the extreme design situation), g_{var}, q_{var}, a_{var} are the variable parameters defined in the form of the histogram calibrated to the load combination in compliance with Eurocode and JCSS requirements (JCSS, 2011).

4. Extreme snow load

The load on a structure due to the snowpack will depend on both snow depth and packing density. The snow map of Slovakia was defined on the base of the last result of the SHMU investigations (Kralik, 2019) in accordance with the Eurocode requirements. The characteristic value of the snow load for the return period 10^4 years is 0.72 kPa (for the depth of snow cover 74 mm). On the base of the probabilistic analysis using the Gumbel distribution the following quantile values of the extreme snow load were defined: 1.269 kPa (50 %) and 1.543 kPa (95 %). The value of the extreme snow load $p_{S.Ex}$=1.543 kPa is 2.1x higher than basic design value.

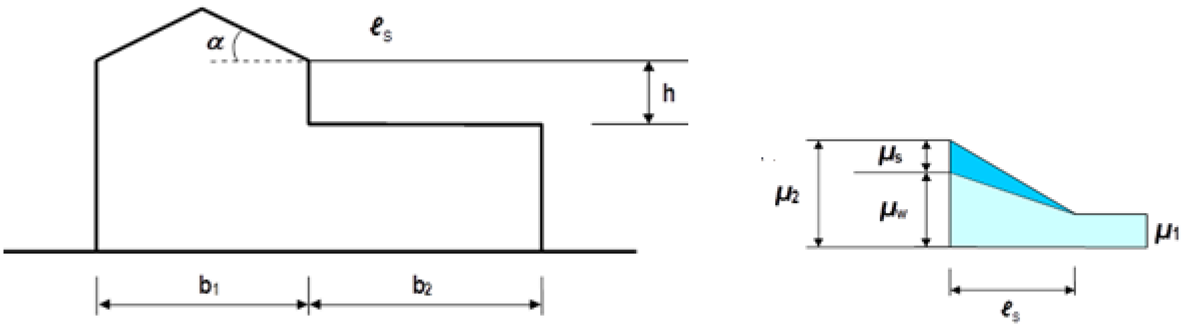

Fig. 2: Model of snow load considering the wind impact.

The snowdrifts were considered in the area between the hall roof and NPP wall in accordance under EN 1991 -1-3 (see Fig. 2). The NPP buildings with the reactor VVER 440/213 consist of the turbine hall, middle building, reactor building and bubble condenser. The building of the power block was idealised with a FEM model consisting of 996.917 elements with 2.666.556 DOF (Fig. 3) in the program ANSYS.

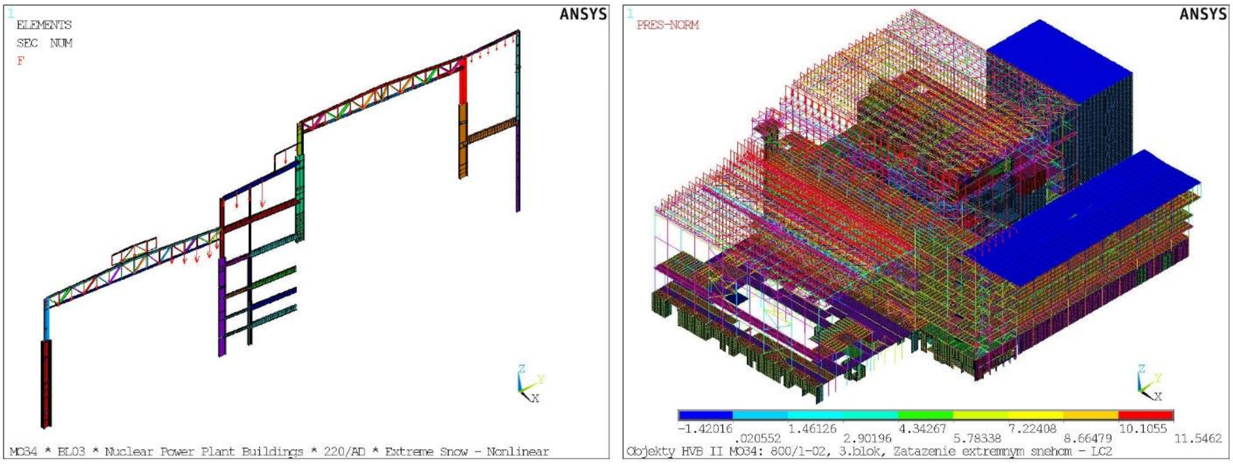

Fig. 3: Calculation Model of the 2D Frame (left); scheme of the 3D Steel Hall (right).

5. Nonlinear analysis

On the base of the linear analysis using the 3D calculation NPP model, the critical frame structures were defined. Next. the maximum extreme loads were calculated from the ultimate state of the critical frame. The limited state of the steel frame was considered to utilize the geometric and material nonlinearity in program ANSYS (Kralik, 2019). The elastic-plastic model of steel material was taken in compliance with the Von Mises yield function. The Newton-Raphson iteration method to solve nonlinear equations was taken. The plasticity model is defined as a multilinear isotropic hardening material model. The failure snow loads were determined on the base of the nonlinear analysis of the steel frame for the characteristic values of the load and material properties. The failure snow load (see Tab. 1) is following

$$p_{S.u} = 1.95 p_{S.Ex} \tag{5}$$

Tab. 1: The limit snow load defined on base of nonlinear solution.

Limit state	Factor η	Load Increment	$p_{s.lim}$ [kPa]	
			50 %	5 %
Elastic	5	0.25	1.846	1.565
Plastic	5	0.48	3.545	3.006

The higher capacity of the frame can be determined by ductility factor k_D considering the plastic and elastic limit state (see Tab. 1)

$$k_D = p_{S.pl} / p_{S.el} = 1.92 \tag{6}$$

6. Fragility curve of the frame

The fragility curve of the hall structure was calculated using the philosophy of the estimation of failure by factor HCLPF (High confidence of low probability of failure) considering the relations (Kralik, 2009, 2019 and NUREG, 1992) following IAEA standards

$$HCLPF(ESL) = k_D \left(R - G - Q\right) / A_{Ex} \tag{7}$$

where ductility factor k_D was conservatively considered by value 1.5 under the IAEA. The probability of the frame failure expressed by relation (7) was determined by the probabilistic analysis using the LHS simulations in program FReET (Novak, 2003). The uncertainties of the input data – action effect and resistance are for the case of the probabilistic calculation of the structure reliability defined in JCSS and Eurocode 1990. The input data are defined by the characteristic values and the variable coefficient (Tab. 1). The probabilistic density of the failure function of the steel frame for the extreme snow is presented in

Fig. 4. The resistance of the steel frame is more times higher than the action effects of the extreme snow. The results from the linear numerical analysis and the idealized fragility curves of the steel hall frame are presented in Fig. 4.

Tab. 2: The histograms of the input data.

	Quantities		Histograms		
Input data	Character. value	Variable value	Type	Mean μ	Deviation σ [%]
Dead load	G_k	g_{var}	*Normal*	1.0	1
Live load	Q_k	q_{var}	*Gumbel*	0.6	25
Snow	P_k	p_{var}	*Gumbel*	0.6	20
Strength	F_k	f_{var}	*Lognormal*	1.0	1
Model	E_k	e_{var}	*Normal*	1.0	5
Resistance	R_k	r_{var}	*Normal*	1.0	5

The 5 % probability of the steel frame failure considering the ductility effects under snow loads is equal to *HCLPF (ESL)* = 1.53 $p_{S.Ex}$ (Kralik, 2019).

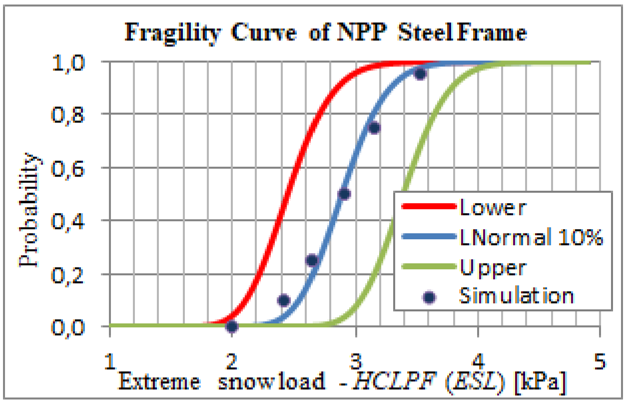

Fig. 4: Fragility curves of the factor HCLPF(ESL) for the extreme snow load.

7. Conclusions

This paper presents the reliability analysis of the steel hall frame resistance due to extreme snow and wind loads. The extreme loads were defined for mean return period equal to one per 10^4 years in accordance with the IAEA requirements for NPP structures (IAEA, 2006, Kralik, 2009, 2019). The ductility was calculated by nonlinear analysis. The limit state (frame collapse) was obtained from deterministic analysis for the ultimate loads $p_{S.u} = 1.95 p_{S.Ex}$. The probability of failure was calculated on program FReET using LHS method (Novak, 2003).

Acknowledgement

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