Vlastislav SALAJKA[1], **Viktor KANICKÝ**[2], **Petr HRADIL**[3]

STUDIE SEISMICKÉ ODEZVY JADERNÉ ELEKTRÁRNY

STUDY OF SEISMIC RESPONSE OF THE NUCLEAR POWER PLANT STRUCTURES

Abstract

The paper deals with the seismic analysis of safety related structures of an operating nuclear power plant. A sophisticated computation model has been developed for the seismic structural analysis using the ANSYS program package. The model involves the complex of all constrained structures of two main production blocks with equipment. In order to get a general view at the seismic load effects, seismic response analysis has been performed using linear response spectrum method. Combinations of dead loads and seismic loads have been considered in the stress assessment of the structures.The results of the performed analyses form a base for residual life prediction of selected structures.

Introduction

At present time the nuclear power plants of VVER-400/213 type operate for over thirty years and there are arising requirements to verify the actual state of structures in order to assess their residual life in general. The basic step in the assessment of the general reliability of an upgraded nuclear plant as a whole involves a revised seismic analysis of safety related structures of the plant.

The up-to-date computing means allow performing an advanced seismic response analysis of the whole complex of mutually constrained structures of a nuclear plant considering the newly specified earthquake loads. Consequently feasible ways of enhancing the earthquake resistance of these structures have been proposed.

Basic assumptions of the seismic analysis

Seismic response analysis of the selected nuclear plant building complex has been performed using an extensive global model including all structures with substantial constraints.

Components of mutual constraints of analyzed structures as well as exposed structural components have been modeled in detail, in order to get directly the loads for eventual redesign. The selection of components has been based on results of both past and revised seismic analyses using models of separated structures with simplified external interactions.

Seismic response of the building complex has been computed using the response spectrum method. The site-specific design response spectrum has been defined in accordance with International Atomic Energy Agency recommendations for seismic re-evaluation of operating nuclear power plants with VVER-type reactors.

Computation model

The computation model includes the reactor hall with the group of surrounding building structures constituting one of the four main production blocks of the nuclear plant. The sophisticated spatial computation model has been developed particularly for the seismic structural analysis using finite element method of discretization. Element library of the ANSYS program package has been used. The structure of the model is obvious from the graphical presentations in Figs. 1 up to 8. General axonometric view of the complete computation model is shown in Fig. 1. A view of the

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[1] Ing., CSc., Ústav stavební mechaniky, Fakulta stavební, Vysoké učení technické v Brně, Veveří 95, Brno, salajka.v@fce.vutbr.cz

[2] Doc., Ing., CSc., Kancelář dynamických výpočtů, Hoblíkova 13, 613 00 Brno, kanicky.v@fea.cz

[3] Ing., Ph.D., Ústav stavební mechaniky, Fakulta stavební, Vysoké učení technické v Brně, Veveří 95, Brno, hradil.p@fce.vutbr.cz

model with upper parts of the structures removed is shown in Fig. 2. Sectional view of the model is shown in Fig. 3. The building complex has a common reinforced concrete foundation plate. The reactor hall and the adjoining accident restraining tower are designed as massive reinforced concrete structures. The buildings adjoining along and across the reactor hall housing the equipment are designed as steel structures. The turbo generator hall situated in front along the reactor hall is designed as a classical steel structure, too.

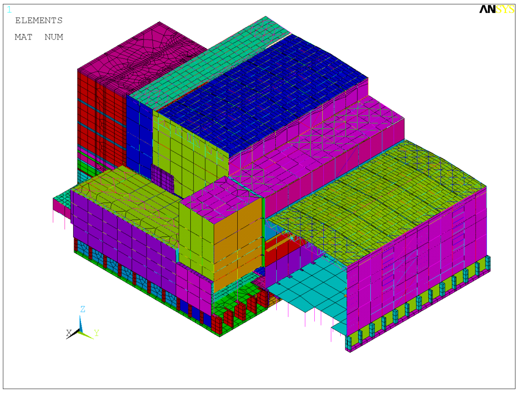

Fig.1

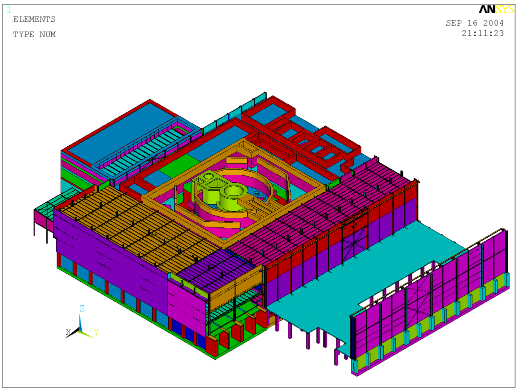

Fig.2

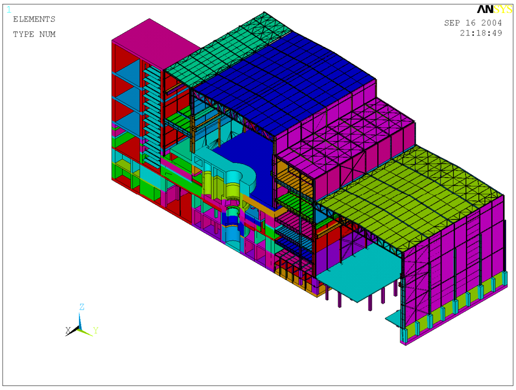

Fig.3

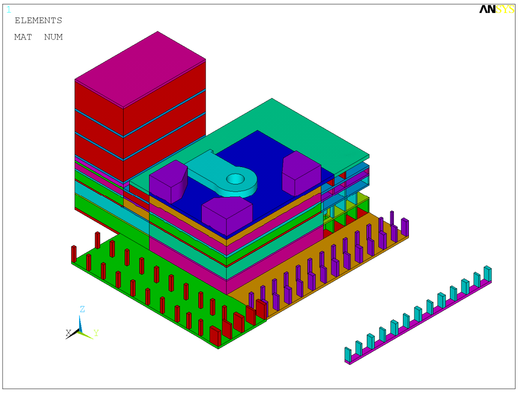

Fig.4

The main reinforced concrete structures have been modeled using spatial finite elements of the type SOLID45 (see Fig. 4). Floors, roof structures, partition walls and sheathings have been modeled by shell elements of the type SHELL43. The axonometric view of the model with removed shell elements is shown in Fig. 5, side view is shown in Fig. 6. Steel structures have been modeled using as a rule beam elements of the type BEAM44. The complexity of the structural systems illustrates Fig. 7 showing the reactor hall roof structure. The roof structure of the engine hall is shown in Fig. 8. Structural details such as anchoring elements, stiffenings, equipment supports, have been modeled using finite elements of the type LINK8. Elements MASS21 have been used to model the concentrated equipment masses.

The computation model for seismic analysis has to represent the spatial distribution of the stiffness and operating mass of the structure to an extent that ensures correct calculation of the significant features of structural seismic response. Consequently, main structural components have been modeled in details, taking into account their stiffness and inertial properties. Non-structural components have been modeled with respect to their inertial properties only. In selected structure regions even secondary structural members have been modeled in detail in order to allow for a correct evaluation of local seismic components of displacements, deformations, forces and stresses.

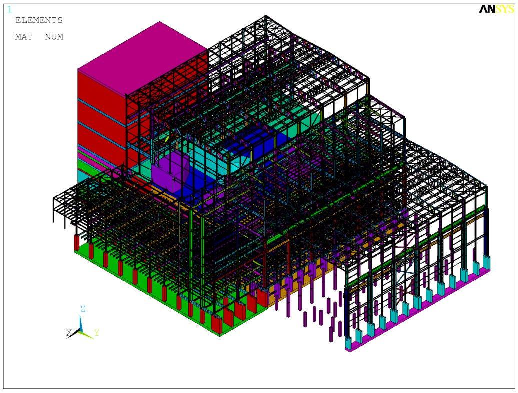

Fig.5

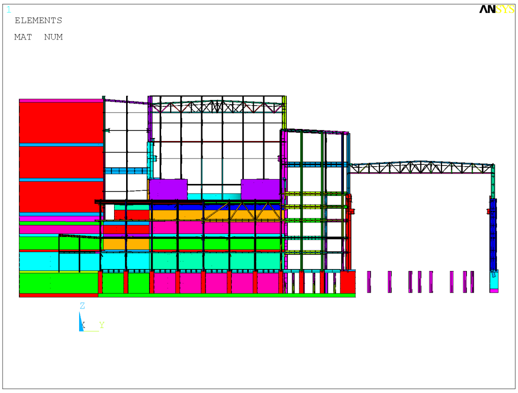

Fig.6

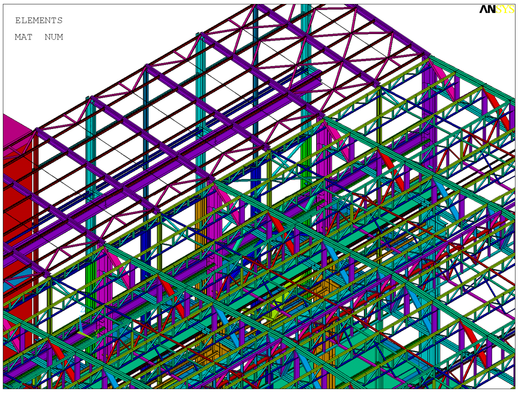

Fig.7

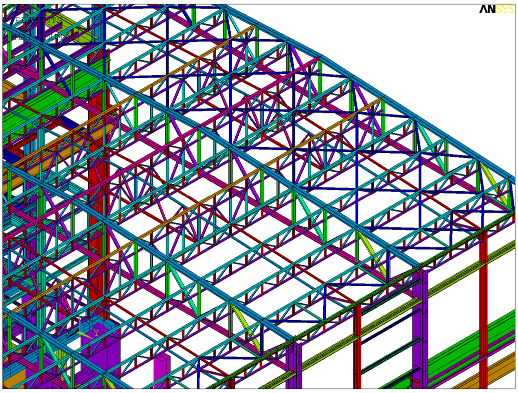

Fig.8

The developed computation FEM-model involves 134983 elements localized by 133270 nodes with 427442 degrees of freedom.

The mechanical energy dissipation in structures has been modeled indirectly using the design response spectra computed for the constant modal damping ratio of 7 %. This corresponds to the fact, that prevailing part of the structural complex is formed by reinforced concrete structures.

The interacting subsoil has not been included in the computation model. Thus, the subsoil - structure interaction has not been explicitly modeled. However, mechanical subsoil properties influencing the structure seismic response have been respected by using the design response spectrum computed for the site subsoil category.

Natural frequencies and normal modes of vibration

In the given case 3500 natural frequencies and normal modes of vibration have been computed in order to satisfy the condition that modal response components of up to 33 Hz have to be considered. For illustration the eleventh normal mode of vibration ($f = 3.33$ Hz) is shown in Fig. 9. The normal mode of vibration corresponding to the natural frequency $f = 4.49$ Hz is shown in Fig. 10.

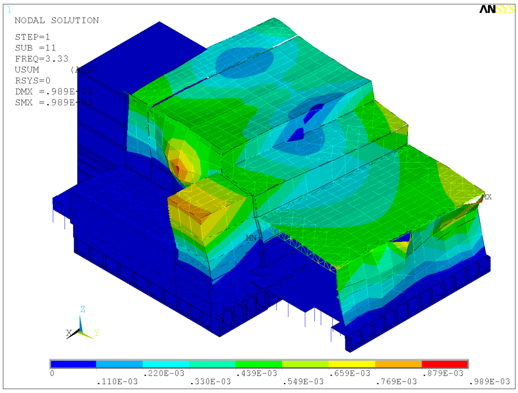

Fig.9

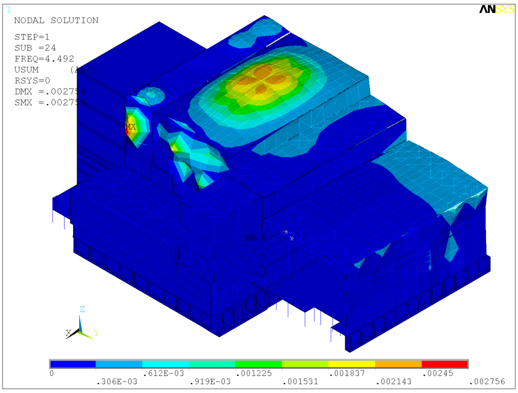

Fig.10

Seismic motion input

Seismic excitation of the computation model has been defined by the acceleration design response spectra for the directions *x*, *y*, and *z*. Spectra have been derived for the reinforced concrete foundation plate (bearing a simplified model of the complex of analyzed structures) subjected to seismic motion defined by three-directional accelerogram. Site subsoil category has been considered. Thus, applied acceleration design response spectra represent, in fact, floor response spectra. The applied response spectrum for the horizontal direction *x* is shown in Fig. 11.

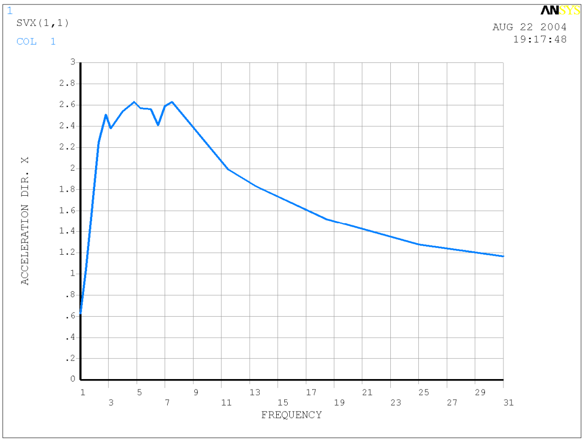

Fig.11

Seismic responses

Seismic responses have been computed by the linear response spectra method separately for the three orthogonal directions *x*, *y*, and *z* using the above mentioned floor acceleration response spectra. Modal superposition method has been used. The SRSS rule has been applied for the combination of modal responses. Normal modes of vibration showing effective modal mass above 0.1 % of the total mass have been considered. The SRSS rule has been also used for the combination of component directional responses to determine the resultant seismic response.

Combination of static and seismic responses

Earthquake resistance of the structures has been assessed using the High Confidence Low Probability of Failure (HCLPF) approach. The HCLPF value expresses the actual limit resistance of the structural component to earthquake load relative to the given earthquake load. The earthquake resistance of the structure has been assessed according to the least value HCLPF of that of all main structural components. For the analyzed case the HCLPF value should be greater than 0.1 g.

In assessing the earthquake resistance of the structure the combined response to both seismic excitation and operating static loads has been considered. The structure response to static loads has been determined using the same computation model as that used in the seismic analysis. The responses have been combined using a simple superposition rule.

To illustrate the response computations the combined response in displacements is graphically presented in Fig. 12. In Fig. 13 the response stresses in structural members of the reactor hall roof structure are shown. The combined response quantities (stresses, displacements, forces) have been individually assessed. Printed presentation of the results using MS EXCEL editor contains in several thousand sheets.

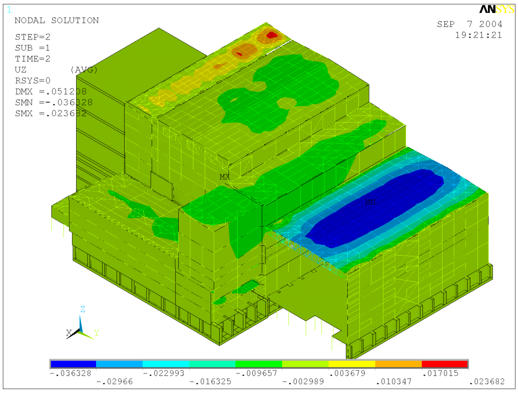

Fig.12

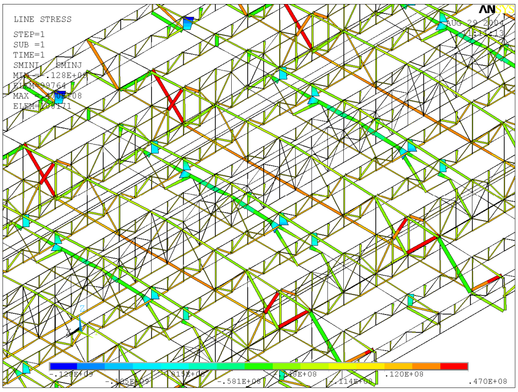

Fig.13

Conclusions drawn from the seismic analysis

The performed seismic analysis has revealed problems with HCLPF seismic resistance assessments in many cases of combined stresses. The strength conditions do not have always linear properties, e.g. with reinforced concrete component loaded eccentrically by tension.

The analysis has revealed high stresses in a number of roof structural members. Although ductility properties present a satisfactory reserve with respect to the load limits, structural modifications have been recommended.

The analysis has shown a more realistic view of the character of seismic loads of the mutual constraints of structures in the complex. Improvements in anchoring the floor steel structures in reinforced concrete walls have been proposed.

Acknowledgements

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