18th International Conference on Structural Mechanics in Reactor Technology (SMiRT 18)
Beijing, China, August 7-12, 2005
SMiRT18-H10-5

FEASIBILITY STUDY OF ENHANCING EARTHQUAKE RESISTANCE OF THE NUCLEAR POWER PLANT DUKOVANY STRUCTURES

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ABSTRACT

The paper deals with the seismic analysis of safety related structures of an operating nuclear power plant. This analysis represents a basic step in the assessment of the general reliability of an upgraded nuclear plant as a whole. At present time nuclear power plants of the VVER-400/213 type operate for over thirty years and there are arising justified requirements to verify the actual state of the structures in order to assess their residual life. The up-to-date computing means allow performing an advanced seismic response analysis of the structures considering the newly postulated earthquake loads. Recently a detailed stress analysis of nuclear structures operated and loaded for decades has been performed. Consequently feasible ways of enhancing the earthquake resistance of structures have been proposed.

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. Solid finite elements have been applied to model reinforced concrete structures, mainly beam elements have been used in modeling steel structures.

In order to get a general view at the seismic load effects, seismic response analysis has been performed using linear response spectrum method. Site-specific response spectra been applied. 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.

Keywords: Earthquake resistance, feasibility study, steel structures, load bearing structures

1. INTRODUCTION

With respect to the newly postulated severed earthquake risk of operating nuclear power plants the problem of assessing their actual earthquake resistance arises. At present time the nuclear power plants of VVER-400/213 type operate for over thirty years and there are arising justified requirements to verify the actual state of the 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. Recently a detailed stress analysis of Dukovany nuclear power plant structures operated for three decades has been performed. Consequently feasible ways of enhancing the earthquake resistance of these structures have been proposed.

2. 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. Study of past time analyses which were based on variant computations of individual structures involving either approximately modeled constraints or assessed constraint forces has revealed large dispersion of results with a conservative selection of them for application. Such an approach has been fruitful in the plant building design phase, but it cannot be applied in the refined process of enhancing an operating building complex.

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.

Seismic analysis has been performed using the computer with the AMD Athlon 64 FX 51 processor with 4 GB RAM and 1000 GB of disk space. The 32 bit version of ANSYS 8.1 running under Windows XP 64 Bit Edition operating system has been used. One complete computation cycle involving the modal analysis, response spectra analysis and the determination of the combined response (without evaluation) has taken about 5 days. The disk space of about 750 GB has been used.

3. 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 model of the structure has been developed exploiting a very extensive set of project drawings supplemented by many revisions. Civil engineering design documentation as well as technical documentation concerning machinery and other equipment has been studied in order to get correct input data.

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 4. General axonometric view of the complete computation model is shown in Fig. 1 - first part. A view of the model with upper parts of the structures removed is shown in Fig. 1 – 2nd image. Sectional view of the model is shown in the Fig. 2 – 1st image. 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.

The main reinforced concrete structures have been modeled using spatial finite elements of the type SOLID45 (see Fig. 2 – 2nd part). 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. 3, side view is shown in Fig. 3 – 2nd part. Steel structures have been modeled using as a rule beam elements of the type BEAM44. The complexity of the structural systems illustrates Fig. 4 showing the reactor hall roof structure. The roof structure of the engine hall is shown in Fig. 4 – 2nd image. 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.

In general, there is no need to use an overall extra fine discretization of the structure. 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.

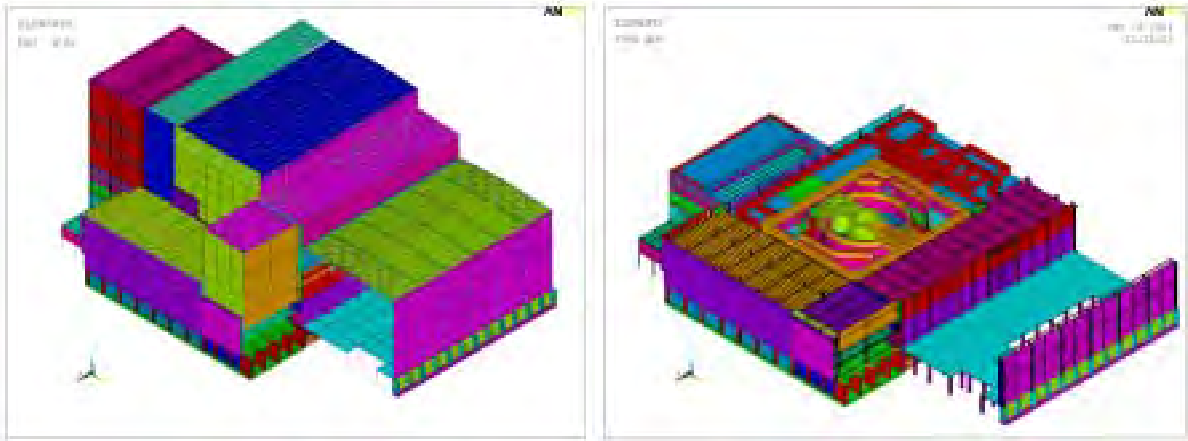

Fig. 1: The FEM model (general axonometric view, sectional plan on the reactor level)

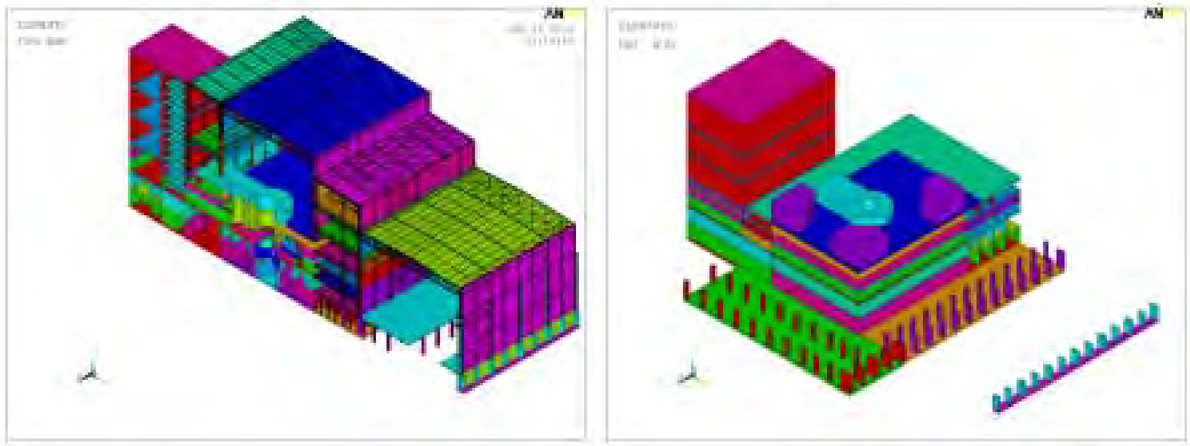

Fig. 2: The FEM model (longitudinal section, sectional plan under the reactor level – solid finite elements)

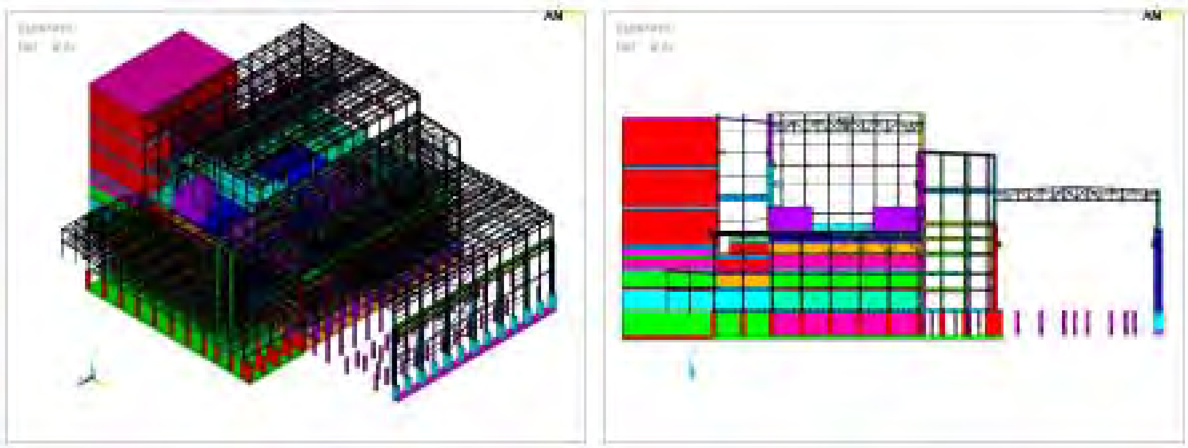

Fig. 3: FEM model (total view – load bearing structures of facade and roof structure, longitudinal section)

However, to fulfill the given task, 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.

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.

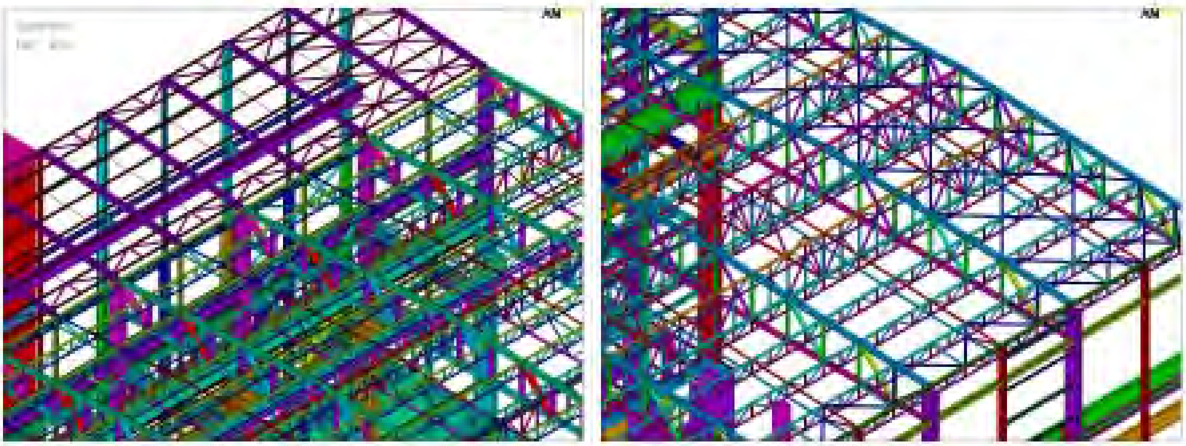

Fig. 4: Details of the roof structures of the generator and engine room

4. NATURAL FREQUENCIES AND NORMAL MODES OF VIBRATION

Determination of a sufficient number of natural frequencies and normal modes of vibration represents the basic step in computing the seismic response by the method of linear response spectra. 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. 5 – 1st part. The normal mode of vibration corresponding to the natural frequency f = 4.49 Hz is shown in Fig. 5 – 2nd image.

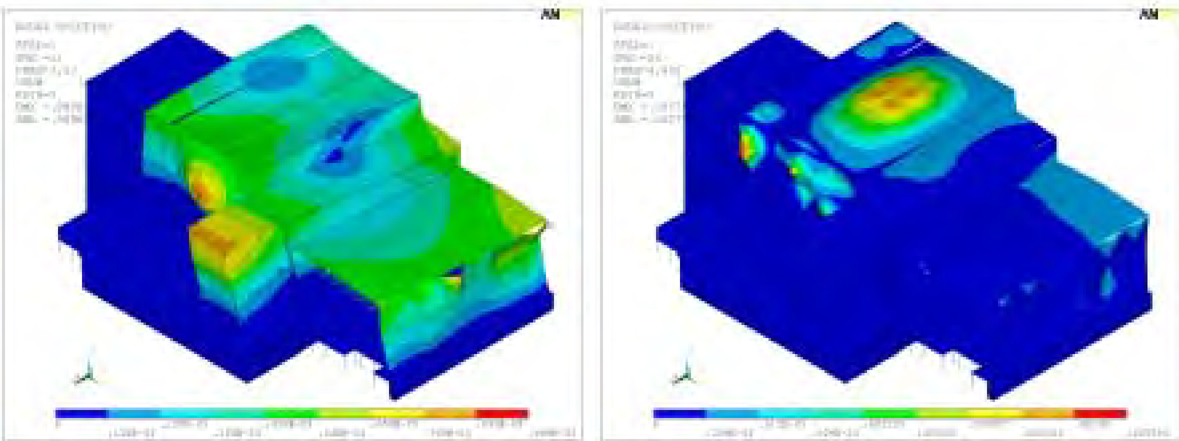

Fig. 5: Normal modes of vibration (11th normal mode – f = 3,33 Hz; normal mode for frequency f = 4,49 Hz)

5. SEISMIC MOTION INPUT

As mentioned above, mass of interacting subsoil has not been included in the computation model. Seismic excitation of the computation model has been defined by the acceleration design response spectra for the directions *x*, *y*, and *z*. Spectra has 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. 6.

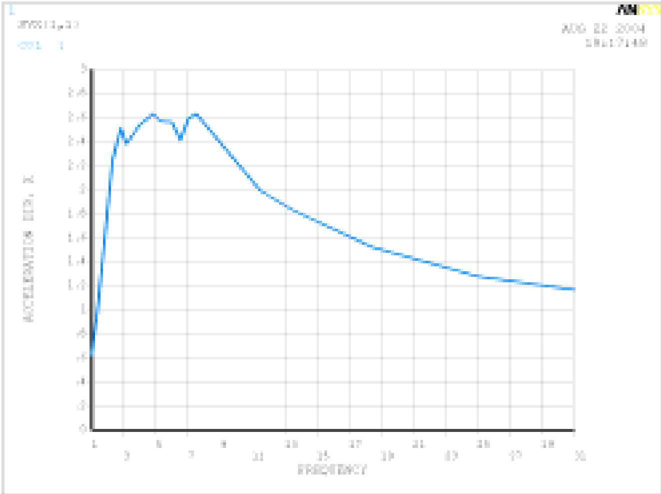

Fig.6: Response spectrum for the horizontal direction

6 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 resultant directional responses to determine the resultant seismic response.

7 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. 7 – 1st image. In Fig. 7 (2nd part) 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.

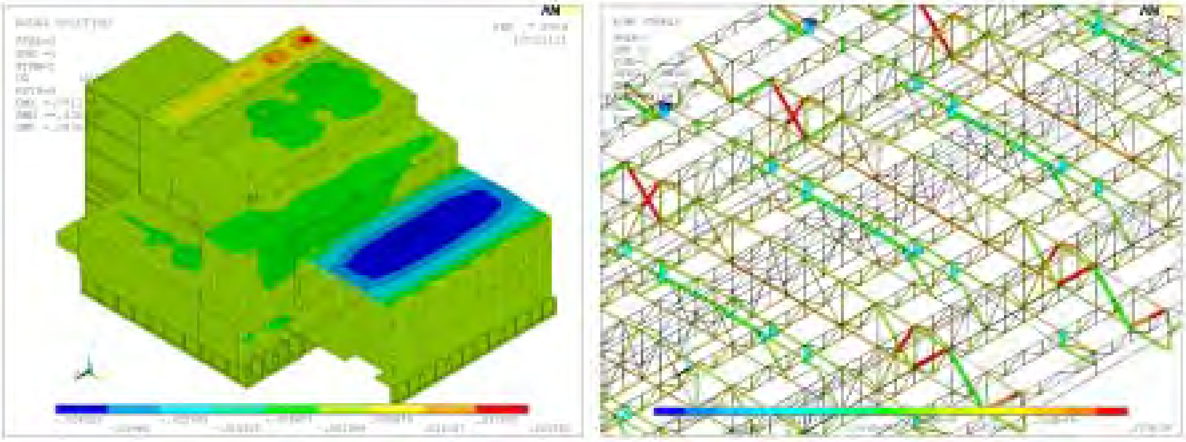

Fig. 7: Examples of combined response – displacements (static and seismic actions)

8 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 on 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

This contribution has been prepared in the frame of the project „Enhancing earthquake resistance of the nuclear power plant Dukovany structures” as well as with support of grant project GA ČR no. 105/04/1424 „Response of structures and buildings to technical seismicity“ and GACR 103/05/292 “Design optimization of progressive concrete structures”.

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