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In-structure response data of the VVER 1000 NPP for the analysis and qualification of M & E components

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ABSTRACT: In accordance with the decisions made at the IAEA Research Coordination Meeting on "Benchmark Studies for Seismic Analysis and Testing of VVER-Type Nuclear Power Plants" (Kozloduy, 13 - 17 June 1994), the institutions involved in the derivation of the in-structure dynamic response of the VVER 1000 reactor building were to compare and evaluate the results obtained by different modeling concepts and calculation procedures with the aim of obtaining the design loading functions (response time histories and spectra) to be used for requalification and upgrading of components and systems located in this building.

Within the framework of these investigations for the reactor building of the VVER 1000 KOZLODUY, parallel calculations were prepared by three institutions participating in this project. The investigations were based on different mathematical models and procedures for consideration of soil-structure interaction effects, but on the same soil dynamic and seismological input data.

The dynamic response results represent the governing loading function for analytical and experimental requalification of all components and systems installed in the reactor buildings of VVER 1000 nuclear power plants located on soft/medium soil sites.

1 INTRODUCTION

At the second Research Coordination Meeting (RCM) in Kozloduy, preliminary results of studies were presented by participants involved in the seismic analysis of the VVER 1000 structures. According to the contributions in the period between the first and the second RCM (Sept. 1993, Paks and June 1994, Kozloduy) the following participants performed work on the VVER 1000 benchmark project.

- EQE Bulgaria Ltd. Sofia, Bulgaria
- Bulgarian Academy of Sciences (BAS)
  Central Lab. for Seismic Mechanics and Earthquake Engineering Sofia, Bulgaria
- Siemens AG, Power Generation Group (KWU)
  Offenbach, FRG in cooperation with
  Atomenergoproject Moscow (Russian Fed.)

The presented investigation methods, mathematical models and dynamic response results for the VVER 1000 were evaluated and discussed at the meeting mentioned above.

It was finally decided to compare the corresponding results obtained by means of different structural models and soil representations with the aim of deriving the final enveloped and smoothed dynamic response data (benchmark response spectra) which should be used for requalification by analysis and testing of mechanical and electrical components and systems.

The aim of this paper is therefore to compare and evaluate the dynamic response results obtained in the framework of the benchmark studies carried out for the VVER 1000 KOZLODUY until now by the working group formed by BAS (benchmark 1), EQE (benchmark 2) and Siemens (benchmark 3).

2 COMPARISON OF ASSUMPTIONS AND INPUT DATA

The seismic and soil dynamic input data as well as drawings of the structure were provided by KOZLODUY Nuclear Power Plant, Kozloduy, Bulgaria [6] and [7]. This information and documentation represent the starting point of all of the benchmark studies (B1 to B3).

The basic seismological inputs (free-field spectra) were determined by two groups of specialists from Bulgaria (NICI) and Macedonia (IZIIS) and, after approval of the input data by an expert commission of IAEA (in June 1992), these data were accepted for use in the benchmark studies of structures located on the Kozloduy site [6].

The seismic input for the KOZLODUY site is mainly defined by the free-field spectrum shown in Figure 1. The maximum horizontal free-field acceleration is defined as 0.2 g and the vertical as 0.13 g.

Based on the information given in Figure 1, artificial time histories were generated by each participant using various programs (i.e. [1] in benchmark 1). However, agreement between the target and computed response spectra was to be checked in all cases to assure compliance with the corresponding requirements.

The soil profile in the vicinity of Unit 5 of KOZLODUY with its respective layer thicknesses is characterized in Table 1. The soil condition of the Kozloduy site may be characterized as soft to medium. Shear wave velocities and density measurements represent the basis for defining the shear moduli of the corresponding layers. In addition to the information mentioned above, results of laboratory tests of the respective soil layers were provided in [7].

However, in the various benchmark calculations slightly different assumptions were used regarding the upper levels of the soil. It can be seen that the geological soil dynamic conditions at the Kozloduy site are rather homogeneous when the layers up to the building embedment level (-7.0 m) are neglected.

2.1 Structural model of benchmark 1 (B1)

A 3D finite element model (Figure 3) was developed in which all load-bearing elements were properly considered taking into account all possible structural interactions. Special attention was paid to the modeling of the internal concrete structure as well as to the modeling of separation joints between the different substructures. The containment was modeled using shell elements. The soil stratum was represented by a system of spring constants and dashpots. The modal damping of the soil-structure system was limited to 30 % of critical damping for the vertical and 15 % of critical damping for the horizontal direction of motion.

2.2 Structural model of benchmark 2 (B2)

A separate stick model was defined for each of the four main parts of the reactor building structure: substructure, outer building, containment and internal structure. The dynamic properties for each of the sticks, except the containment, were obtained using the EQE computer program WALLY [9]. WALLY calculates the stiffness and mass parameters for structures comprised of shear walls and floor slabs. The masses are lumped at each floor elevation and consist of mass contributions from both the slabs themselves and the contributory portion of the connected walls. The axial, shear and bending stiffness of the wall systems as well as the centers of rigidity are calculated by the program. Masses, mass moments of inertia, and centers of mass are also calculated for each floor elevation.

The individual models of each of the four substructures were then assembled into a single model, with appropriate constraints (rigid links) at elevation 13.20 m where the four models coincide (Figure 4). The soil was represented by frequency-independent impedance functions obtained using the program SUPLEM [8] on the basis of earthquake-adapted shear moduli. The embedment effects were considered with and without side walls bonded to the backfill.

2.3 Structural model of benchmark 3 (B3)

Considering the geometric shape, stiffening and mass distribution of the reactor building under concern, as well as the frequency content of the dynamic excitation, the use of an equivalent beam model was assessed to be admissible and appropriate (Figure 5). The beam model includes the outer structure, the containment, the inner structure and the basemat structure as a fully connected total system. The equivalent stiffnesses and masses were determined with the aid of a computer [5] on the basis of engineering inputs and assumptions defined for each floor and region.

The arrangement of additional nodal points was derived from the locations at which guides or supports are installed for the piping systems. The soil was represented by frequency-independent as well as frequency-dependent impedances obtained by SASSI [2] on the basis of earthquake-adapted shear moduli derived by SHAKE [3]. The influence of embedment effects were considered.

3 COMPARISON OF RESULTS

The dynamic analyses were conducted using the different finite element codes [2], [8] and [10].

The programs solve the equation of motion in the frequency [2] and [8] or time [10] domain. The response at any node in the model was calculated for simultaneous excitation in the X1/X3 and X2/X3 directions. In determining the acceleration response spectra, the frequency intervals suggested by USNRC Regulatory Guide 1.122 were employed.

The structural responses were calculated in the form of acceleration response spectra for the characteristic regions of the building shown in Figure 2.

In order to compare and discuss the dynamic response values obtained by means of the different calculations and model concepts (coupled or decoupled models of soil and structure), the response spectra obtained for typical elevations (basemat, structure elevation +13.2 m, primary system support, level roof of the outer building and upper region of the containment) were compared (see Figures 6 to 13).

4 CONCLUSIONS

When analyzing the compared spectra, the following can be observed:

- The dynamic characteristics (eigenfrequencies and mode shapes) obtained by all three models are in good agreement due to the realistic representation of soil-structure interaction effects as well as the capabilities of the total building structure.
- The results obtained by benchmark 2 and 3 (frequency-dependent impedances) are generally in good agreement for the horizontal and vertical directions.
- In calculation B1 the horizontal response obtained shows somewhat higher values due to cut-off of modal damping.
- The vertical response (in B1) generally leads to much higher values due to cut-off of damping and consideration of local effects at the floors in the 3D model.

In general, the analysis based on frequency-dependent impedance functions (B2 and B3) yielded lower accelerations, especially in the frequency range above the fundamental frequency, compared to the accelerations obtained through the conventional time domain approach (B1).

5 REFERENCES

[1] AGA, Generation of Artificial Spectrum Compatible Acceleration Time Histories, Siemens KWU Version 6/1990

[2] SASSI, A Computer System for Dynamic Soil-Structure Interaction Analysis, Siemens KWU Version 1/1991 (Original source M. Tabatabaie-Raissi, J. Lysmer, University of California, Berkeley)

[3] SHAKE, Earthquake Response Analysis of Horizontally Layered Sites, Siemens KWU Version 6/1990 (Original source B. Schnabel, J. Lysmer, B. Seed, University of California, Berkeley)

[4] STRUDYN, General Computer Program for Linear Elastic Static and Dynamic Analysis of Structures, Siemens KWU Version 3/1991

[5] STABGEN, Generation of Equivalent Beam Models, Siemens KWU Software Version 9/84

[6] Initial Data of Kozloduy NPP site, Part I NPP Kozloduy, October 1993

[7] Initial Data of Seismic Input and Soil Condition of Kozloduy NPP Site, Extension to Part II Soil Conditions Kozloduy June 1994

[8] Computer Program SUPLEM, EQE Document AA-QA-041

[9] Computer Program WALLY, EQE Document AA-QA-000

[10] NISA, A Linear Static and Dynamic Analysis Program, Engineering Mechanics Research Corporation, USA

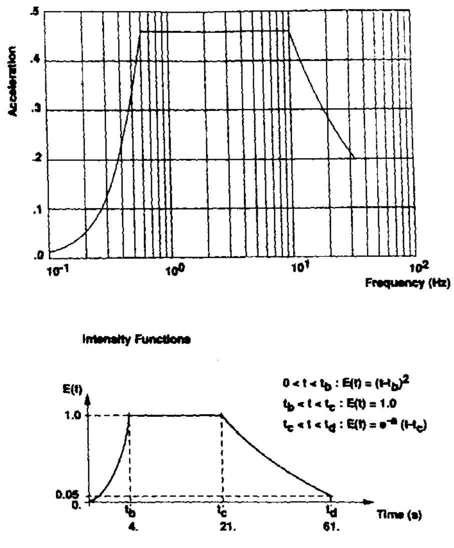

Fig. 1 Free-Field Spectrum (5% Damping) for the Site KOZLODUY

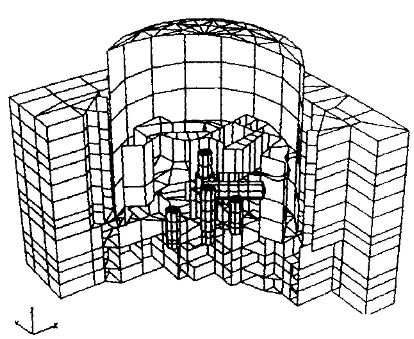

Fig. 3 VVER-1000 MW KOZLODUY
3D Plate Element Model (Benchmark 1)

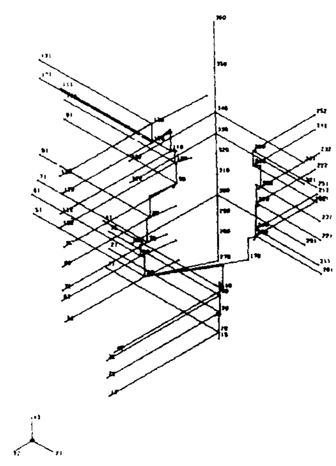

Fig. 5 VVER-1000 MW KOZLODUY
Beam Element Model (Benchmark 3)

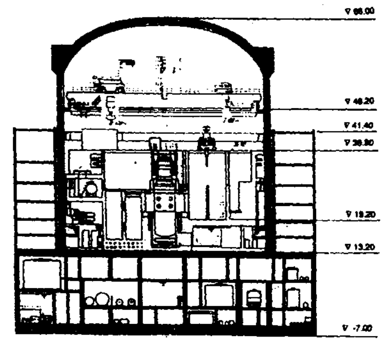

Fig. 2 VVER-1000 MW Reactor Building KOZLODUY,
Section and Characteristic Regions

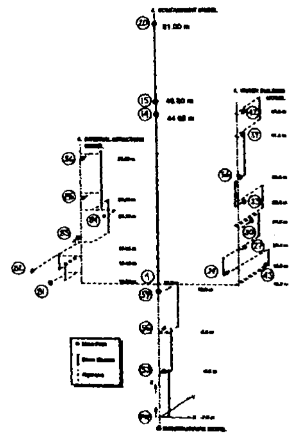

Fig. 4 VVER-1000 MW KOZLODUY
Beam Element Model (Benchmark 2)

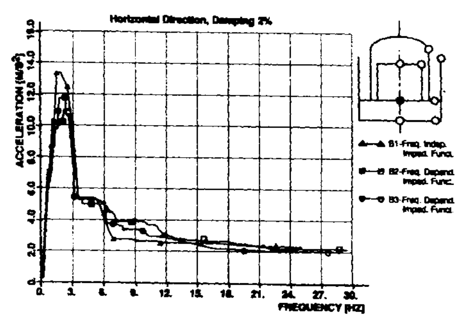

Fig. 6 VVER-1000 MW Reactor Building KOZLODUY,
Upper Level of Base Structure

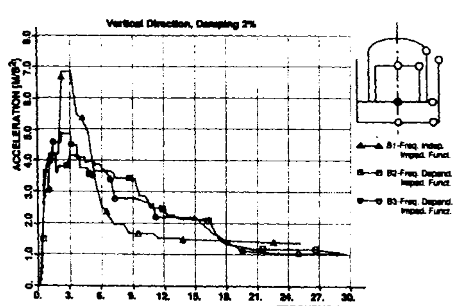

Fig. 7 VVER-1000 MW Reactor Building KOZLODUY,
Upper Level of Base Structure

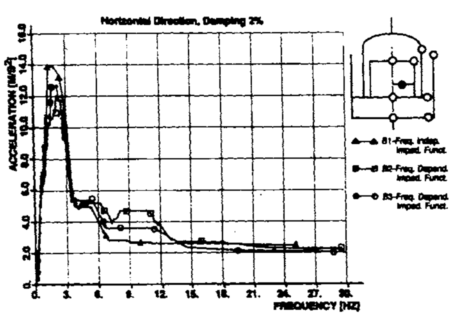

Fig. 8 VVER-1000 MW Reactor Building KOZLODUY, Primary System Support Level

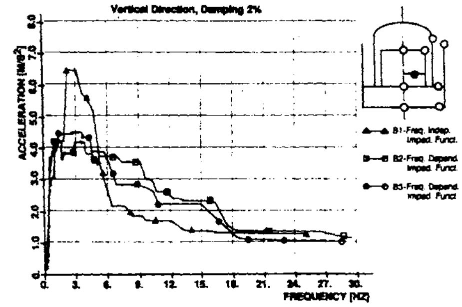

Fig. 9 VVER-1000 MW Reactor Building KOZLODUY, Primary System Support Level

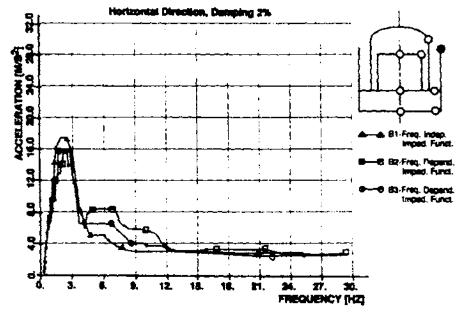

Fig. 10 VVER-1000 MW Reactor Building KOZLODUY, Upper Level of Auxiliary Building

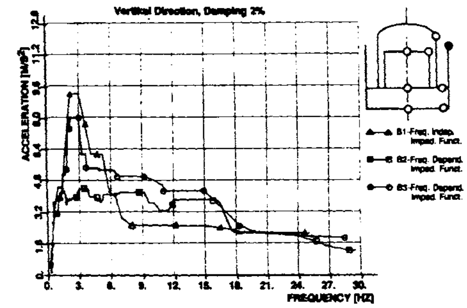

Fig. 11 VVER-1000 MW Reactor Building KOZLODUY, Upper Level of Auxiliary Building

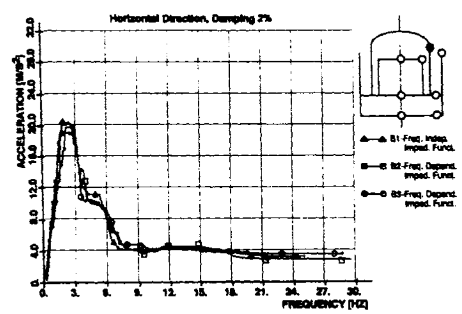

Fig. 12 VVER-1000 MW Reactor Building KOZLODUY, Building Kran Support

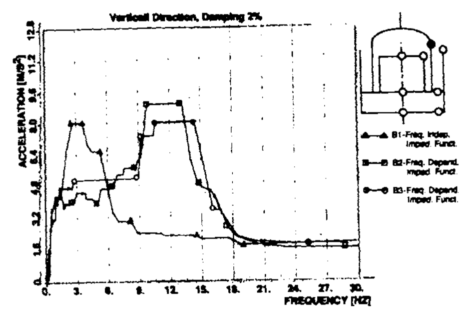

Fig. 13 VVER-1000 MW Reactor Building KOZLODUY, Building Kran Support

LAYER THICK-NESS m	FROM-.. TO... m	DENSITY t/m^3	POISSON'S RATIO	S-WAVE VELOCITY Vs m/s	P-WAVE VELOCITY Vp m/s	TYPE OF SOIL
3.0	0.0- 3.0	1.60	0.42	170	470	Loess
4.0	3.0- 7.0	1.60	0.44	175	540	Sandy loess
6.5	7.0- 13.5	1.80	0.41	450	1180	Clayey loess
5.0	13.5- 18.5	2.00	0.45	500	1600	Gravelly sand
3.0	18.5- 21.5	2.00	0.45	500	1600	Compact clay
9.5	21.5- 31.0	2.12	0.45	500	1600	Sand-fine clayey
11.0	31.0- 42.0	2.10	0.47	430	1700	Sandy clay
42.6	42.0- 84.6	1.92	0.45	520	1700	Sand-fine clayey
19.4	84.6-104.0	1.98	0.44	550	1700	Sand-fine clayey
29.0	104.0-133.0	2.01	0.46	450	1600	Sandy clay
18.0	133.0-151.0	1.98	0.44	540	1600	Marly clay
24.0	151.0-175.0	2.00	0.44	580	1750	Marly clay
29.0	175.0-204.0	1.96	0.43	530	1470	Marly clay
20.0	204.0-224.0	1.98	0.37	630	1470	Marly clay
21.0	224.0-245.0	2.00	0.40	680	1700	Clayey marl
20.0	245.0-265.0	1.96	0.40	705	1760	Clayey marl
	265.0-	2.00	0.40	>705	>1760	Clayey marl

Tab. 1 Soil Layers and Data at Site KOZLODUY