COMPARISON OF DETERMINISTIC AND PROBABILISTIC RESPONSE OF CRITICAL STRUCTURES

KRİTİK YAPILARDA DETERMİNİSTİK VE PROBABİLİSTİK DAVRANIŞLARIN KARŞILAŞTIRILMASI

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ABSTRACT

The seismic safety assessment of critical structures is of great importance. Reevaluation of the seismic behaviour of a nuclear power plant is performed using deterministic and probabilistic techniques for dynamic analysis. Original procedures are developed including all peculiarities of the site and structure taking into consideration the specific seismic conditions. Two kinds of acceleration response spectra at different structure levels are determined and discussed. Conclusions concerning the seismic safety of the structure are drown.

INTRODUCTION

The seismic safety assessment of critical structures such as nuclear power plants, large dams, etc. is a very difficult and important task. It is a part of the risk analysis establishing the potential accident risk for critical structures near high population concentration. Development of safety design requirements for nuclear power plants (NPP) in the last 25 years took place in a subjective, deterministic framework. Little use was made of the quantitative probabilistic risk assessment (PRA) because the respective techniques for analyzing nuclear power plants were not fully developed. In the early 1960s the idea of reactor safety study based on the PRA techniques was proposed and introduced rapidly in the practice.

Safety-related structures and equipment in a nuclear power plant are designed to withstand the effects of a Safe Shutdown Earthquake (SSE) and an Operating Basis Earthquake (OBE). The ground response spectra for the SSE and OBE, the damping ratios for different structures, the procedures for soil-structure interaction

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nalysis, and for structural and piping response analysis as well as the load ombinations and stress allowables are specified in different codes and in the NRC tandard Review Plan (1,2,3,4,5). The design practice is intended to assure that tructures and equipment respond essentially within elastic range. The design of new lants is based on conservative methods. Very often the existing plants are eanalyzed for seismic margins when the definition of seismic hazard, ground notion, or other characteristics have been revised. The objective of a seismic margin assessment (SMA) is to determine whether a plant can resist with high confidence of a low probability of failure a specified earthquake level greater than the SSE. Deterministic and probabilistic methods can be applied. The SMA differs from the PRA which goal is to develop distribution of in-structure response spectra and structural forces for selected earthquake levels. In the probabilistic analysis only probabilistic methods are used. The main difference is that the SMA needs an earthquake review level and the PRA needs seismic hazard curves and uniform hazard spectra.

The analysis steps of the deterministic seismic response analysis for margin evaluation are the following: definition of seismic input as a single deterministic spectrum, definition of structural and soil models with best estimated properties and also the upper and lower bound stiffnesses of the soil, deterministic response analysis for the three soil cases and envelopes of responses. The respective steps of the probabilistic response analysis are: definition of seismic input with median values as well as COV and explicit variability, definition of structural and soil models - median, COV and explicit variability, simulation analyses and finally calculation of median, standard deviation, and COVs of responses.

Deterministic and probabilistic seismic response analyses are performed of units 5 and 6 of NPP Kozloduy. Original procedures are developed combining the techniques of the PRA and SMA analyses and the peculiarities of the VVER-1000 reactor structure. The acceleration response spectra at different levels of the reactor building applying two completely different techniques are determined. A short comparison only of the results is discussed in the paper. The philosophy of the two kinds of response analyses is outside the scope of present study.

DETERMINISTIC RESPONSE ANALYSIS

Reevaluation and upgrading of NPP Kozloduy has started after 1977 Vrancea earthquake. New SSE level was defined and all units are reanalyzed.

The seismic motion at free-field is given as an acceleration response spectrum at 5% damping shown in Fig.1 and maximum acceleration 0.20g (horizontal component) for SSE level and return period of 1000 years. The vertical acceleration is 50% of the horizontal one. The spectrum has been determined as an envelope of spectra for many earthquakes took place in the region with radius of 320 km. In addition time histories (three components) are generated on the base of the spectrum.

The soil characteristics of "free-field geological column" for the site are established experimentally. A soil model with characteristics at low strain is developed. The strain compatible properties are established also experimentally.

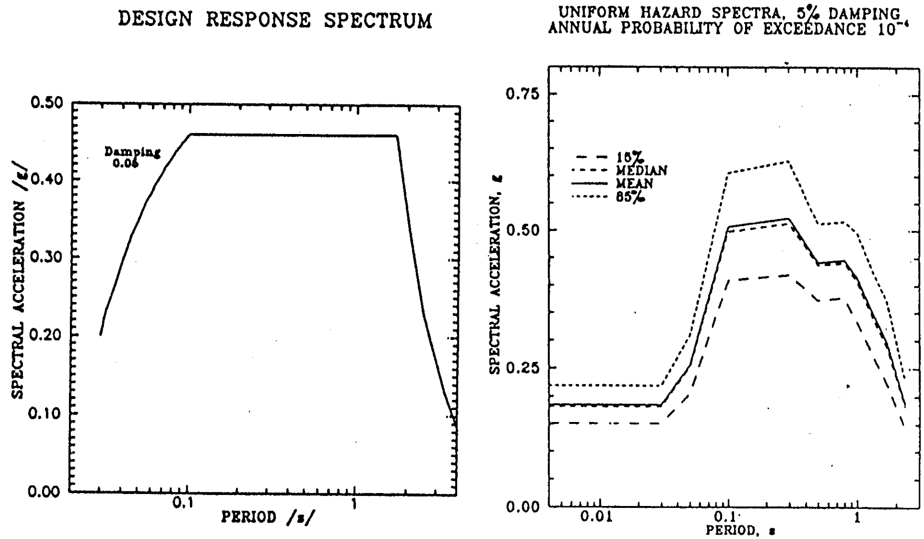


Figure 1. Acceleration response spectra at free-field - deterministic and probabilistic

Three cases of soil characteristics are studied - mean, "soft soil" with decreased G-moduli and "hard soil" with increased G-moduli. By deconvolution and convolution of the free-field time histories the respective time histories at foundation level are determined. The response spectra of horizontal components for the cases of soft and hard soil are shown in Fig.2. The free-field spectrum called design spectrum is also given.

The soil-structure-equipment model consists of: springs and dashpots representing the soil and 3D finite element model of the complicated spatial structure with a part of the main equipment (other part is included by the respective masses lumped at different points of the model).

The acceleration response spectra at different points of the model are determined. Some of those spectra for soft and hard soil are shown in Fig.3 and 4.

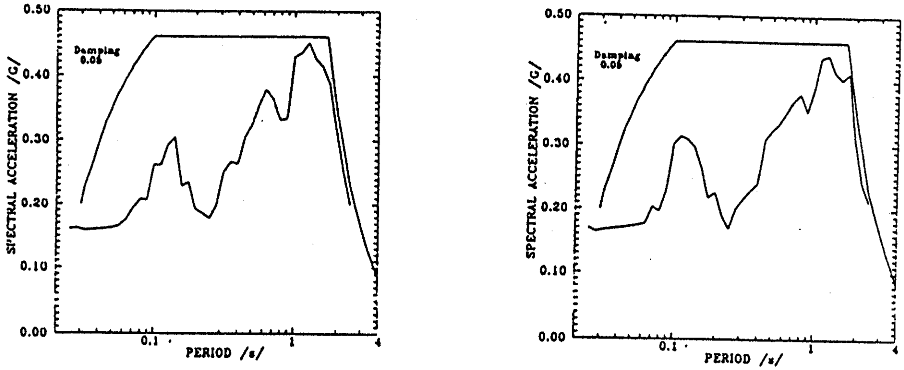
PROBABILISTIC RESPONSE ANALYSIS

The first step of this analysis is the seismic hazard assessment. The random and model uncertainties are taken into account. Hazard curves for the maximum acceleration at the site are derived. The equal hazard acceleration response spectra for annual probability of exceedance of 0.001, 0.0001 and 0.00001 are computed. The mean, median, standard deviation and geometric deviation (log-normal distribution) values are obtained. For the second value of hazard the spectra are shown in Fig.1.

For response analysis the seismic hazard is presented by a set of modified artificial accelerograms - 10 accelerograms (three components) for each level of hazard. The number 10 is applied as a frequency in a Latin Hypercube Experimental Design Procedure (LHCED). For the sake of the necessary statistics for generation of the accelerograms an analysis is performed over 90 pre-selected accelerogram components recorded from real earthquakes (6,7). Generation of the 10

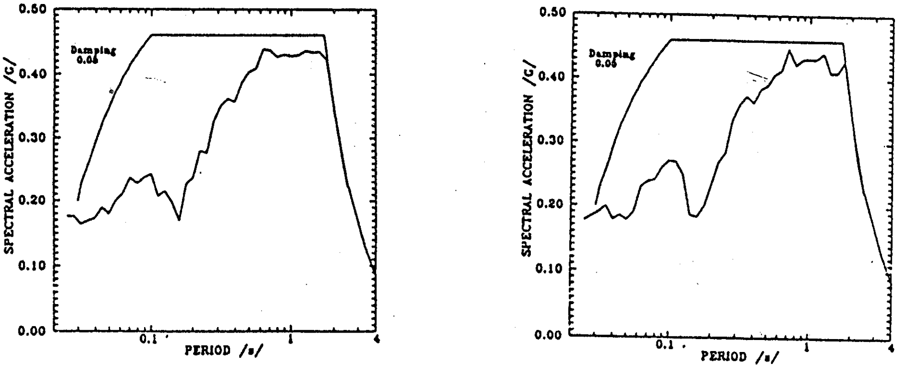
at Foundation Level and Design Spectrum
N - S Component
Soft Soil

at Foundation Level and Design Spectrum
E - W Component
Soft Soil



at Foundation Level and Design Spectrum
N - S Component
Hard Soil

at Foundation Level and Design Spectrum
E - W Component
Hard Soil



ANNUAL PROBABILITY OF EXCEEDANCE 10^{-4}
FOUNDATION LEVEL -7.0 m
HORIZONTAL COMPONENTS L

ANNUAL PROBABILITY OF EXCEEDANCE 10^{-4}
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HORIZONTAL COMPONENTS T

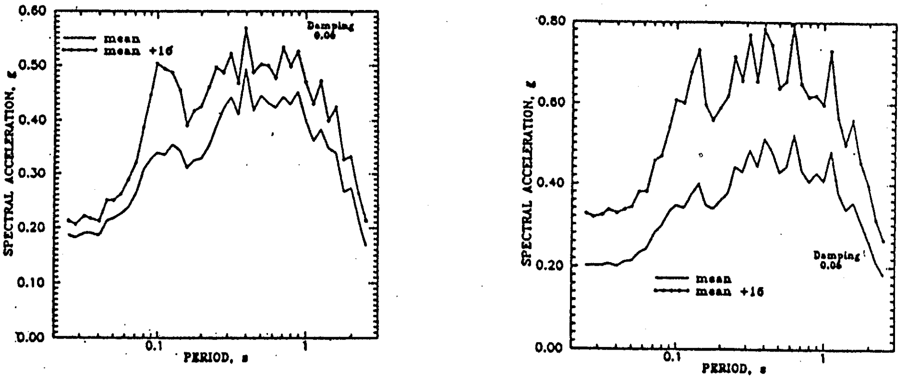


Figure 2. Acceleration response spectra at foundation level - deterministic and probabilistic

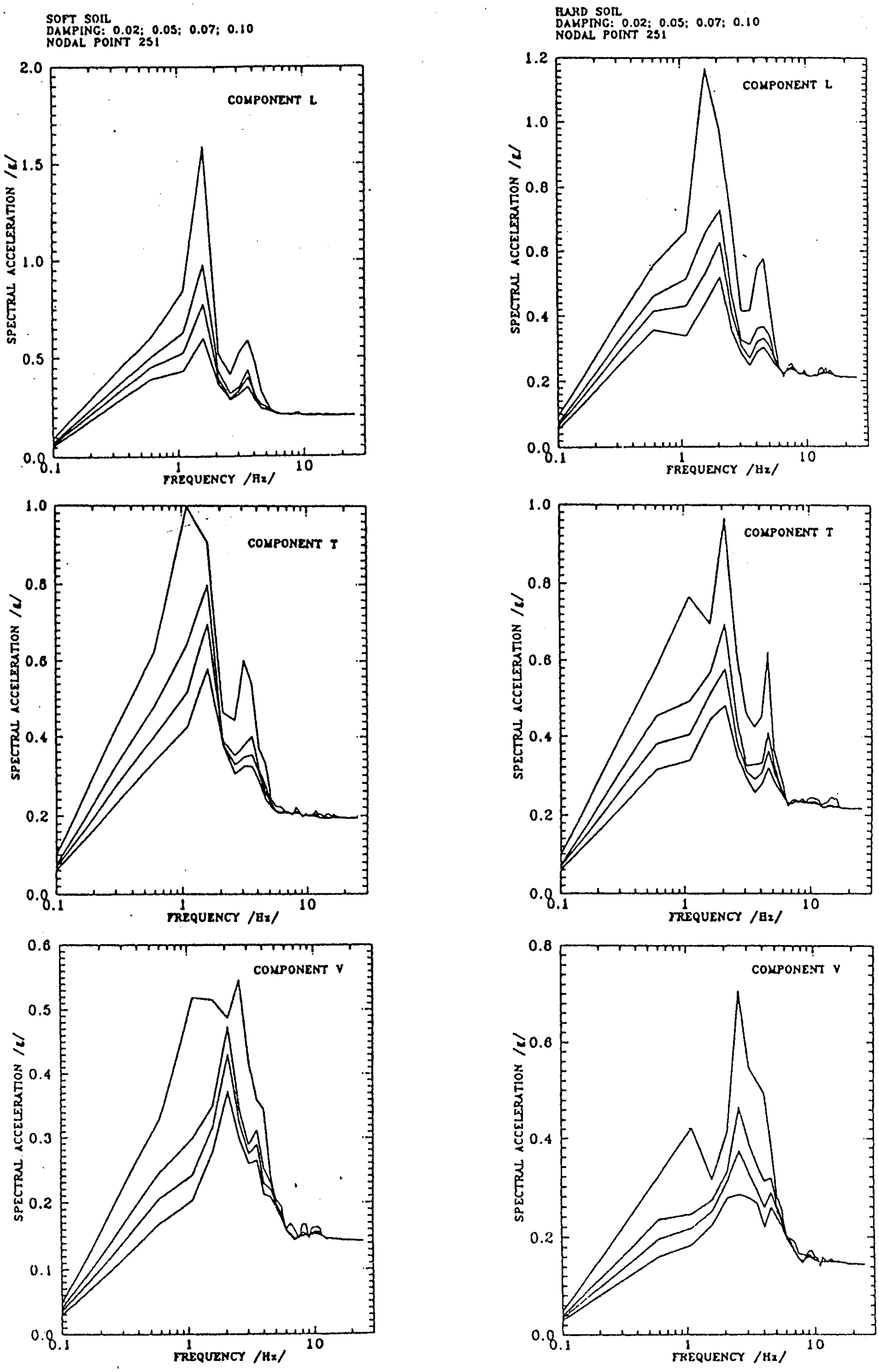


Figure 3. Deterministic acceleration response spectra

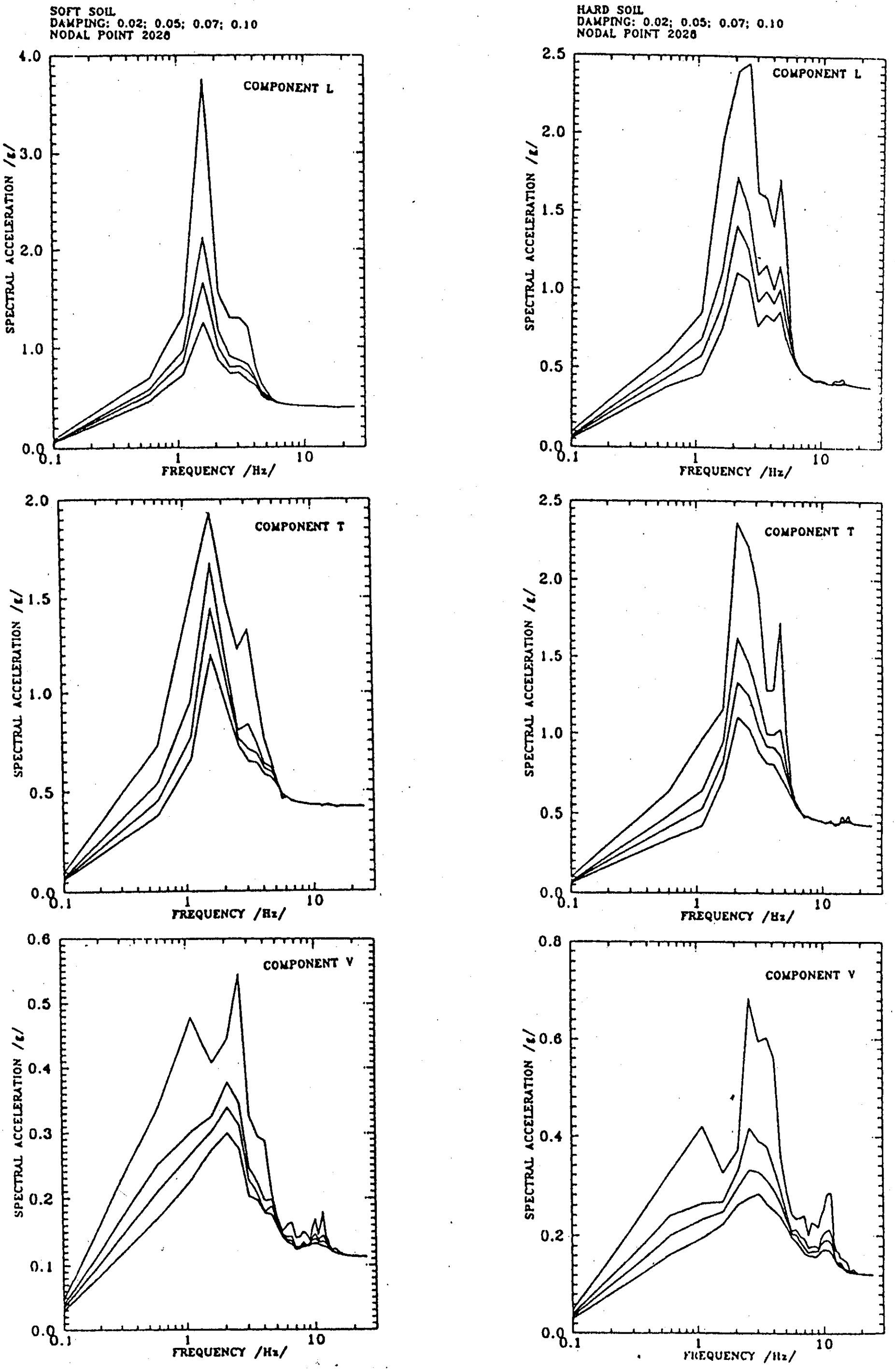


Figure 4. Deterministic acceleration response spectra

accelerograms is performed according to the LHCED procedure regarding the response spectrum, i.e. the spectra of the generated accelerograms match the mean value and the variation of the uniform hazard spectrum. Those free-field spectra should be transferred to the foundation level.

A probabilistic model of the local geology is compiled. Ten profiles are generated by LHCED procedure. By deconvolution the free-field accelerograms are transferred to the foundation level. This procedure is performed for each level of hazard. The horizontal components of the response spectra of those accelerograms are shown in Fig.2 for annual probability of excellence 0.0001.

A 3D finite element model of the structure is developed. In the soil-structure modelling the soil is represented again by springs and dashpots (6). The damping in the model is computed according to the composite damping rule. In the structure are used 4%, 5% and 7% of the critical damping respectively for the three hazard levels with 50% variation and in the soil the damping in vertical direction is assumed to be 60%, 70% and 80% (variation 50%), in horizontal direction - 60% of vertical damping, for rocking - 50% and for torsion - 30% of the vertical damping. The modal analysis is performed using 255 natural modes up to the frequency of 25 Hz. Variation of 30% of the natural frequencies is applied. The response is computed for all ten three-components accelerograms involving the above mentioned variations and for three levels of hazard. Then a statistical analysis is done for each level and mean and standard deviation values of responses are determined. Three components of floor acceleration response spectra are computed. Some of them are shown in Fig.5.

COMPARISON OF RESPONSE SPECTRA

The analysis of the floor response spectra determined by deterministic and probabilistic techniques shows many common features. There is not significant difference in the frequency content of the two kinds of spectra. The hardening of the soil does not change the shape of the first horizontal component (L component) but there is a small change in the shape of the T component - the maximum spectral values are for shorter frequency in the case of soft soil. The second spectral peak is more perceptible in probabilistic spectra.

At all levels the horizontal components at different points are identical. There is difference in the vertical components because of the rotational effects. This difference is more significant in upper levels. This peculiarity could be seen in deterministic and probabilistic spectra and is illustrated in Fig.3, 5 and 6. The nodal points 190 and 251 are at level 0.00 m. The nodal point 2028 is at the centre of the shell roof (cupola) at level 66m.

There are some differences between the two kinds of spectra (greater in the spectra at the free-field and at the foundation level and smaller in the maximum spectral values). The first horizontal component (L) has a maximum value for soft soil higher than the respective value for hard soil. The maximum spectral value of the probabilistic spectra are between those of deterministic ones, nearer to the hard soil spectra. Only at the low elevations the probabilistic maximum spectral value is smaller than those for soft and hard soils.

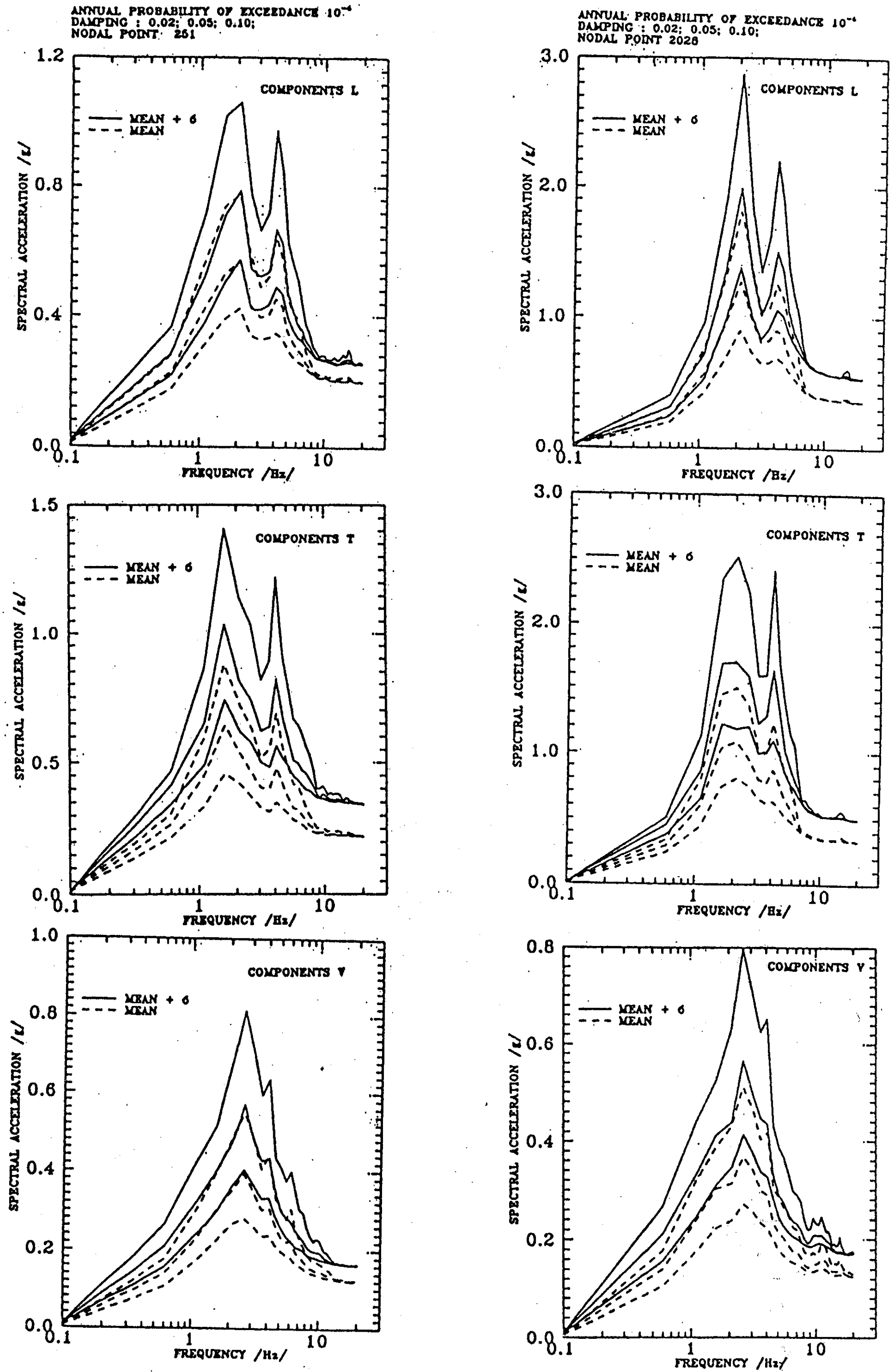
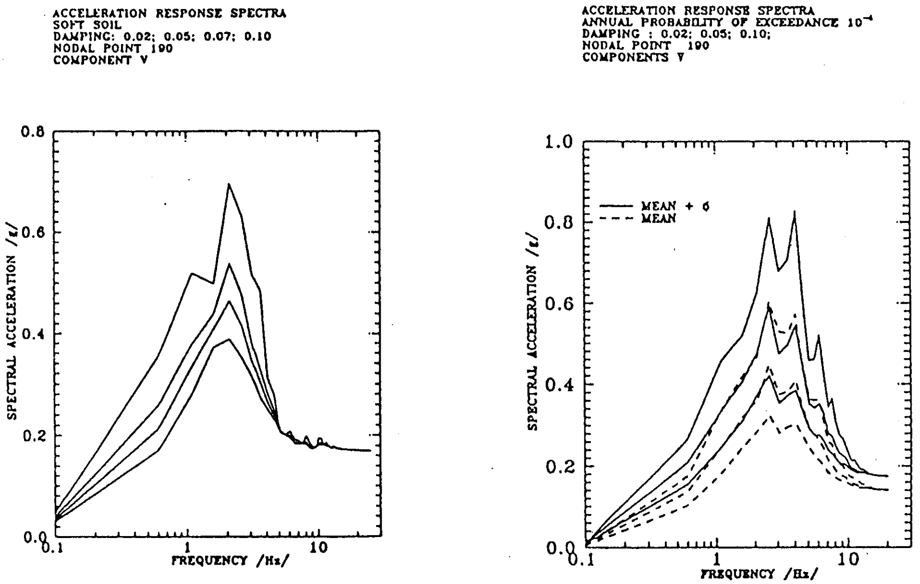


Figure 5. Probabilistic acceleration response spectra



ACCELERATION RESPONSE SPECTRA
SOFT SOIL
DAMPING: 0.02; 0.05; 0.07; 0.10
NODAL POINT 190
COMPONENT V

ACCELERATION RESPONSE SPECTRA
ANNUAL PROBABILITY OF EXCEEDANCE 10^{-4}
DAMPING : 0.02; 0.05; 0.10;
NODAL POINT 190
COMPONENTS V

Figure 6. Vertical components of deterministic and probabilistic response spectra

The difference of the maximum spectral acceleration in the second horizontal component for two cases of deterministic spectra is very small the values for hard soil being larger than those for soft soil. The respective probabilistic values are larger than deterministic ones nearer to the values for hard soil. The exception is again in the spectra at low structure levels. The same effect can be seen in vertical components.

CONCLUSION

The analysis of the acceleration response spectra determined by deterministic and probabilistic techniques shows a good dynamic behaviour of the reactor building. The two kinds of spectra have a common characteristics. A considerable influence of the soil and foundation on the seismic behaviour of the VVER-1000 reactor building is clearly demonstrated - the first natural modes of vibrations are predetermined by the soil-structure interaction. The seismic capacity of the building could be assess as high. This conclusion is drown on the base of the results obtained applying completely different procedures for response computation. For critical structures the seismic safety assessment should be performed using deterministic and probabilistic methods of investigations.

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