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Deterministic and probabilistic response of units 3/4, NPP Kozloduy

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ABSTRACT

Deterministic and probabilistic analyses of the structures of units 3 and 4 in NPP Kozloduy are performed. They are carried out separately considering the review level earthquakes and local seismicity at the NPP site. Using a 3D FE model of the structure and input motion represented by acceleration time histories, in-structure acceleration response spectra are generated. A comparison between the deterministic and probabilistic spectra is done and respective conclusions and recommendations are given.

INTRODUCTION

The deterministic and probabilistic seismic response analyses use different techniques. The analysis steps of the deterministic analysis 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 structure and soil models also with median, COV and explicit variability, simulation analyses and finally calculation of median, standard deviation, and COVs of responses.

Deterministic and probabilistic seismic response analyses of units 3 and 4 of NPP Kozloduy are performed. Original procedures are developed combining the techniques of the two kinds of response analyses and the peculiarities of the WWER-440 reactor structure.

DEFINITION OF THE FREE-FIELD SEISMIC MOTION

In recent years the seismic safety of all structures in NPP Kozloduy has been re-evaluated. New seismic characteristics called "review level earthquake" (RLE) characteristics were estimated and used in the deterministic analysis. The seismic motion at free-field is given as an acceleration response spectrum with 5% damping shown in Fig.1 and maximum acceleration of

0.2g (horizontal component) for SSE level and return period of 10000 years. The vertical acceleration is accepted to be 50% of the horizontal one. The spectrum has been determined on the basis of a seismic analysis of the region with radius of 320km around the NPP site. In addition a three-component acceleration time history is generated using the free-field spectrum as a target spectrum.

The first step of the probabilistic analysis [1] is the seismic hazard assessment taking into account the random and model uncertainties. Hazard curves for the maximum acceleration at the site are derived. The equal hazard acceleration response spectra for annual probability of exceedance of 10^{-3}, 10^{-4}, and 10^{-5} are computed [2]. The mean, median, standard deviation, 15% and 85% values are obtained. For the 10^{-4} hazard level the spectra are shown in Fig. 2. On the basis of the mean equal hazard spectrum for each seismic hazard level a set of 10 acceleration response spectra is generated applying the Latin Hypercube Experimental Design (LHCED) procedure. Then those spectra are used as target spectra for generation of three-component acceleration time histories (30 acceleration components for each level).

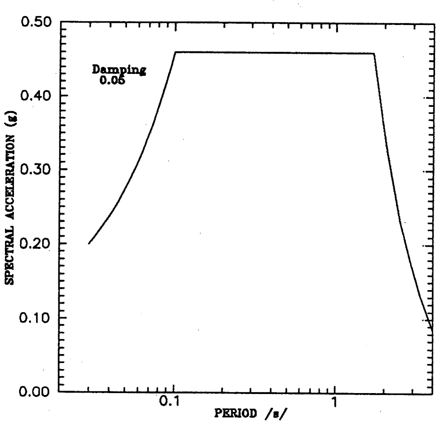

Fig. 1. Free-field design (RLE) response spectrum

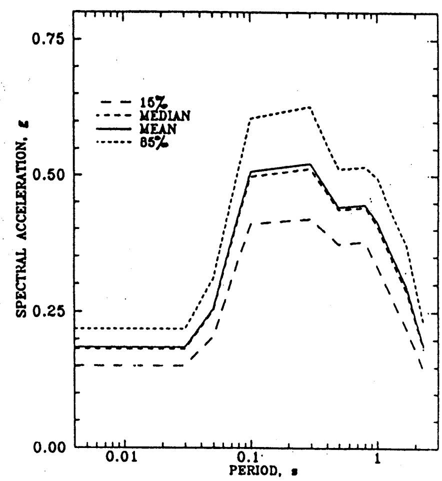

Fig. 2. Free-field uniform hazard spectra

Separately the seismic characteristics due to local earthquakes (in a region with a radius of 30km) are defined [3]. As a result of the seismic hazard analysis the maximum horizontal acceleration is evaluated as 0.16g for annual probability of exceedance 10^{-4}. The maximum vertical acceleration of 0.13g is assessed after a statistical processing of a large number of real accelerograms recorded in other regions. The free-field acceleration response spectra (horizontal and vertical components) are determined.

SEISMIC INPUT MOTION AT FOUNDATION LEVEL

The free-field seismic motion is transferred to the structure foundation level taking into consideration the modifying effect of the local soil conditions. For the deterministic analysis a soil model with characteristics at low strain (experimentally established) is developed. Three cases of soil characteristics are studied - average, "soft soil" with decreased G-module and "hard soil" with increased G-module. The strain compatible properties are also determined experimentally. Applying the equivalent linear method by a deconvolution procedure the free-field acceleration time histories are transformed into seismic input motion at foundation level. The respective acceleration response spectra for average soil characteristics (marked as design or RLE) are shown in Fig. 3 and 4. In the same figures are given the response spectra for the local seismic excitation (SINTH1,SINTH2, SINTV) derived in a similar way. The different frequency content of the vertical components as well as the higher maximum spectral acceleration of the "local" spectrum are clearly expressed.

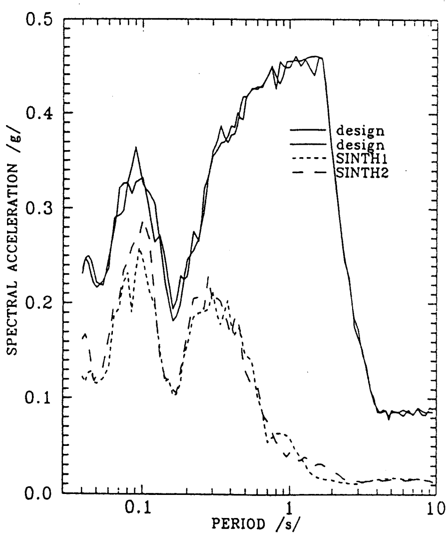

Fig. 3. Acceleration response spectra at foundation level, damping 5%, horizontal components

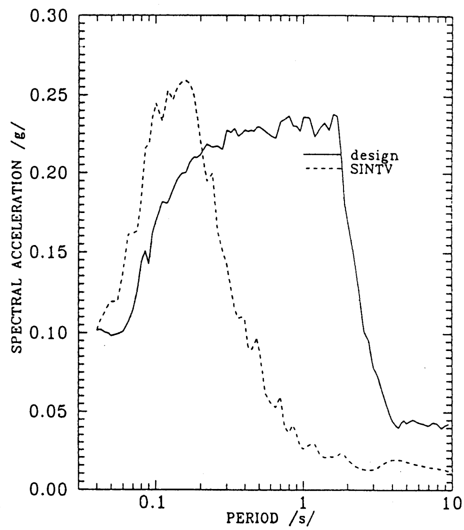

Fig. 4. Acceleration response spectra at foundation level, damping 5%, vertical components

For the probabilistic analysis a probabilistic model of the local geology is compiled [2,4]. For each seismic hazard level ten profiles are generated by LHCED procedure. A set of 10 strain compatible soil properties is also generated. By deconvolution the free-field acceleration time histories are transferred to the foundation level (for each seismic hazard level 10 three-component accelerograms). The mean and mean plus one standard deviation acceleration response spectra are obtained. For the seismic level with annual probability of exceedance 10^{-4} the spectra are shown in Fig.5. The difference between the deterministic and probabilistic seismic input motion could be seen comparing Fig. 3, 4, and 5.

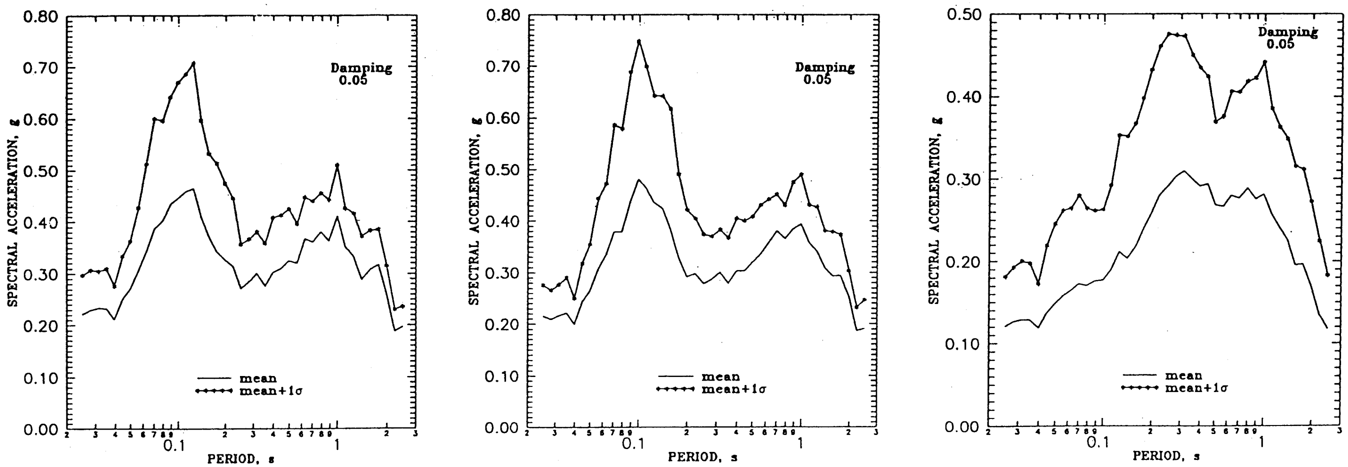

Fig. 5. Acceleration response spectra at foundation level, annual probability of exceedance 10^{-4}

DETERMINISTIC AND PROBABILISTIC RESPONSE OF THE STRUCTURE

A 3D finite element model of the structure is developed (Fig. 6). It is used in the two kinds of analyses. In the soil-structure modelling the soil is represented by springs and dashpots. The damping in the model is computed according to the composite damping rule. In the probabilistic analysis the damping in the structure and in the soil is different for the three hazard levels. A variation of 50% is assumed. The natural frequencies of the structure are varied 30%.

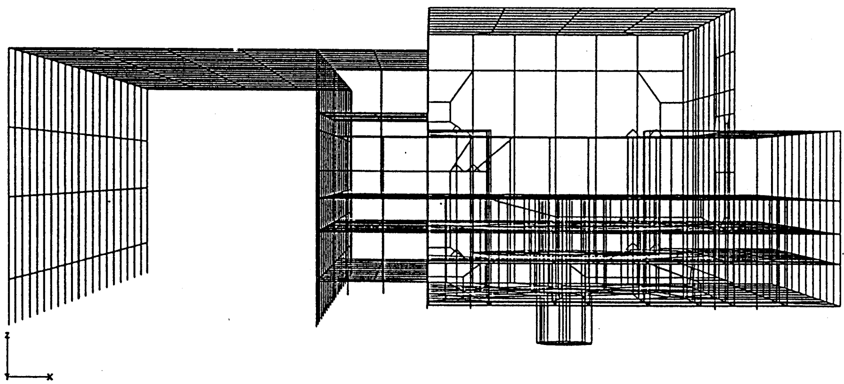

Fig. 6. 3D finite element model of the structure

The response of the structure is computed. The deterministic in-structure acceleration response spectra are generated at many locations important for the equipment as well as for the structure itself. The spectra at two nodal points of the structure model (smoothed and broadened) from RLE (design) characteristics are shown in Fig. 7 and 8. In the same figures are given the response spectra from local earthquakes.

In the probabilistic analysis the response is computed for all three seismic hazard levels. Applying for each level ten three-component acceleration time histories at foundation level the in-structure acceleration response spectra are generated at the same location as in the deterministic analysis. Then a statistical processing is performed and mean and mean plus one standard deviation response spectra are determined. In Fig. 9 and 10 are shown acceleration response spectra at the same places as in Fig. 7 and 8.

CONCLUSION

The analysis of the in-structure response spectra determined by deterministic and probabilistic techniques leads to the following conclusions:

1. In the deterministic response spectra the local earthquakes produce a considerable vertical component (Fig.4) - higher than the RLE spectrum.

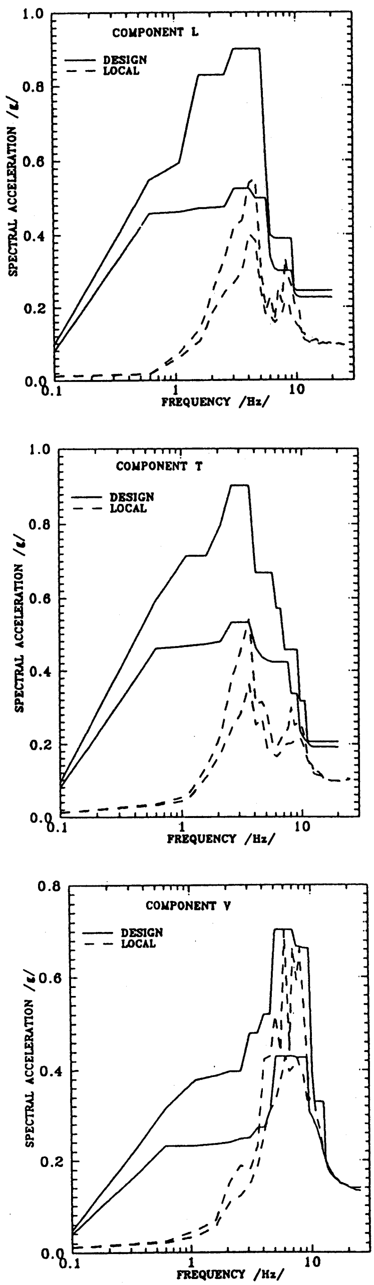

Fig. 7. Deterministic acceler. response spectra damping:0.02; 0.05, nodal point 188

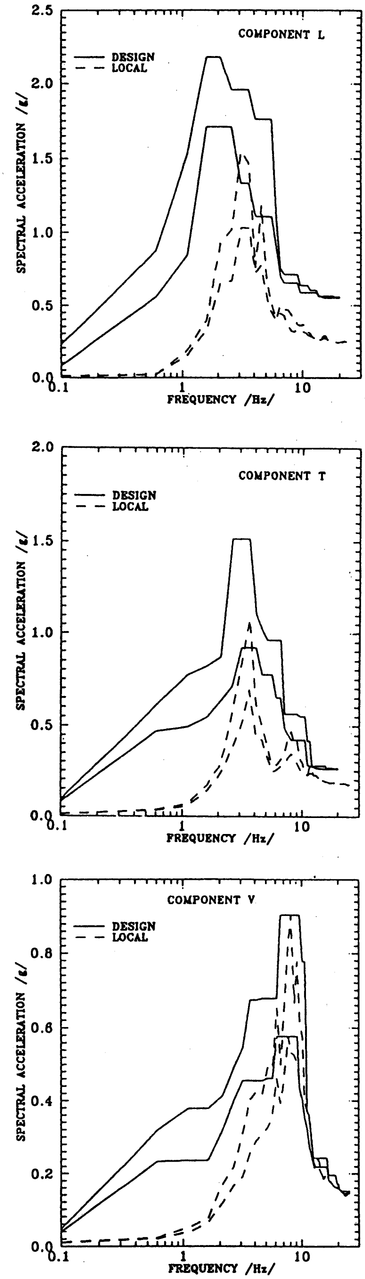

Fig. 8. Deterministic acceler. response spectra damping:0.02; 0.05, nodal point 980

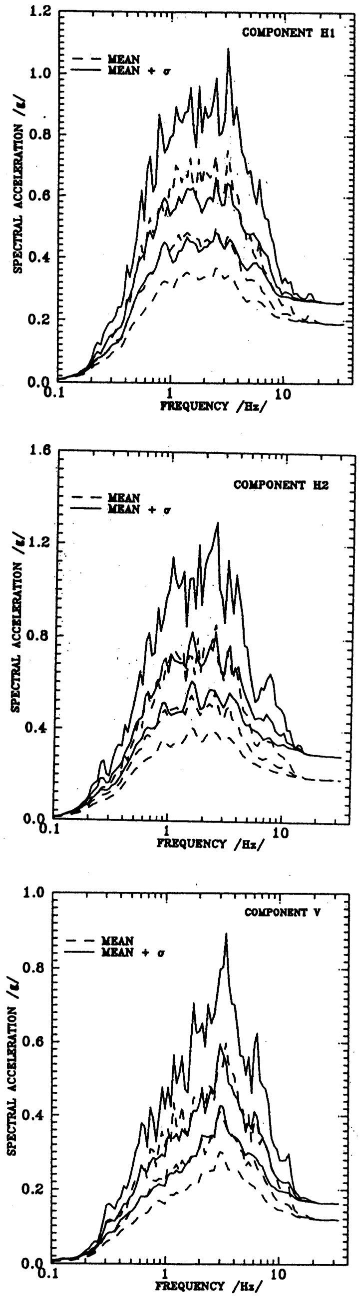

Fig. 9. Probabilistic acceler. response spectra, annual probability of exceedance 10^{-4} damping:0.02; 0.05, nodal point 188

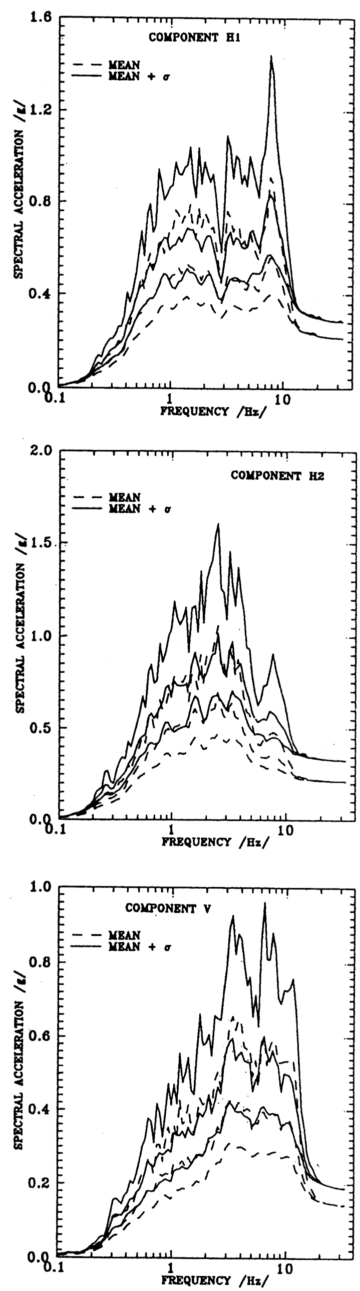

Fig. 10. Probabilistic acceler. response spectra, annual probability of exceedance 10^{-4}, damping:0.02; 0.05, nodal point 980

2. In the probabilistic response spectra this effect is reduced because the probability of occurrence of local earthquakes is small.

3. The long-period spectral values of the free-field deterministic spectrum are higher than those of the corresponding probabilistic spectrum. The deterministic spectrum represents an envelope of many real spectra and there is only one event producing the large long- period spectral values. In the probabilistic spectrum this event has only a small contribution.

4. There is not a great difference between the deterministic and probabilistic in-structure response spectra because the combination of the effects of RLE and local earthquakes on the deterministic spectra make them similar to the probabilistic ones. A difference could be obtained for different limitations of the damping. In the deterministic analysis the radiation damping is limited and in the probabilistic analysis such limitation is not done. However the results are similar because the radiation damping has small influence on the response of the WWER-440 reactor structure. For this structures the probabilistic spectra could be obtained by scaling of the deterministic spectra.

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