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Calculated and Measured Blast Responses of Kozloduy Unit 5 Reactor Building

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Abstract
This study is a part of the IAEA coordinated research program "Benchmark study for theSeismic Analysis and Testing of VVER Type NPPs"and reports the numerical simulation of the blast test for Kozloduy nuclear power plant beginning from the recorded free-field response and computing the structural response at various points inside the reactor building. The full-scale blast tests of the Paks and Kozioduy NPPs took place in December 1994 and in July 1996. During the tests the plants operated normally. The instrumentation for the tests consisted of 52 recording channels with 200 Hz sampling rate. The blast tests consisted of detonating 100 kg charges in 50-meter deep boreholes at 2.5-km distance from the plant. The response of 3D structural model for reactor building was analyzed in the frequency domain.The comparison of measured and calculated results gave information about the suitability of the selected analysis approach for the investigated blast type loading.

1 INTRODUCTION

The NPP Kozloduy is located in a region influenced by different seismic sources. Long-distance sources of intermediate depth as well as shallow long-distance and shallow near-field sources are contributing to the site seismicity. In 1992 the seismic characteristics at the NPP site were re-evaluated. On the basis of the regional seismicity studies in a zone with radius of 320 km around the site the characteristics of the review level earthquake (RLE) were established. They are as follows: peak ground acceleration of 0.2g and to 0.1 g, respectively, for the horizontal and vertical components for level SL2 earthquake with annual probability of exceedance 10-4. In addition, the envelope ground acceleration response spectrum at 5% damping was developed. On the basis of the ground response spectrum the acceleration time histories in three orthogonal directions were generated. The maximum spectral accelerations are in a period range from 0 to 1. 7s. The ground response spectrum is same for the horizontal and the vertical components of the free field ground motion, i.e. there is not difference in the frequency content. The effect of local earthquakes was of great interest. In order to study the local seismicity the zone with a radius of 30 km around the NPP site was investigated. The seismic hazard analysis was carried out using different alternative assumptions for uncertain parameters such as attenuation, maximum and minimum magnitudes, magnitude-frequency relation and spatial distribution of the seismicity inside the zone. As a result 96 hazard curves for the maximum acceleration were obtained. The mean, median and different percentile hazard curves were developed assuming lognormal distribution. Thus the mean peak ground acceleration due to the local seismicity was assessed to be 0.128g and the respective 85% percentile value is 0.162g for the annual frequency of 10^{-4}.The acceleration response spectra on the free field of NPP site for local earthquakes are established on the basis of acceleration time histories recorded at small epicentral distance. Because of the lack of such records at the site 43 three-component time histories from other countries are selected. The parameters for selection are: focal depth from 0 to 15 km, expected magnitude M=4.5 with variation of 0.5 (i.e. in magnitude range of 4 to 5), epicentral distance from 0 to 30 km, and soil type "soft" to "average". The response spectra of the accelerograms are computed and then they are statistically processed. The ratio between peak horizontal to vertical components is established to be 1.23. The mean normalised response spectra is scaled to 0. 16g for horizontal to 0.13g for vertical component. The vertical response spectrum due to the local earthquakes is larger than the RLE spectrum and the higher frequency character of the near-field ground motion is clearly expressed. The review spectra are used as target spectra for generation of a three-component acceleration time history. The envelope of the time history is assumed to have a trapezoidal shape with rising ramp represented by parabolic function and decaying ramp represented by exponential function. The total duration of 20s and 2s duration of the intensive part of time history is adopted and three statistically independent ground motion components were generated. The time histories generated on the free field surface are deconvoluted to the foundation level. The soil characteristics as well as the strain compatible soil properties were established experimentally. The deconvolution procedure is performed with the aid of equivalent linear method.

2 FOUNDATION SOIL CHARACTERISTICS

The summary of the soil investigations at Kozloduy site is given in the Table 1:

Table 1 Soil parameters of the Kozloduy site

Layer id	Material	Thickness	Density	Damping ratio	Shear wave velocity	Poisson ratio
		m	kN/m^3		m/s	
1	medium sand	2.0	18.0	0.02	490	0.40
2	medium sand	4.0	23.0	0.02	380	0.36
3	gravelly sand	2.8	20.0	0.02	500	0.45
4	gravelly sand	1.7	22.7	0.02	600	0.45
5	gravelly sand	10.0	19.0	0.02	680	0.45

3 LOCATION OF MEASURING POINTS

The spatial locations and directions of the measuring points are given in the following sketch.

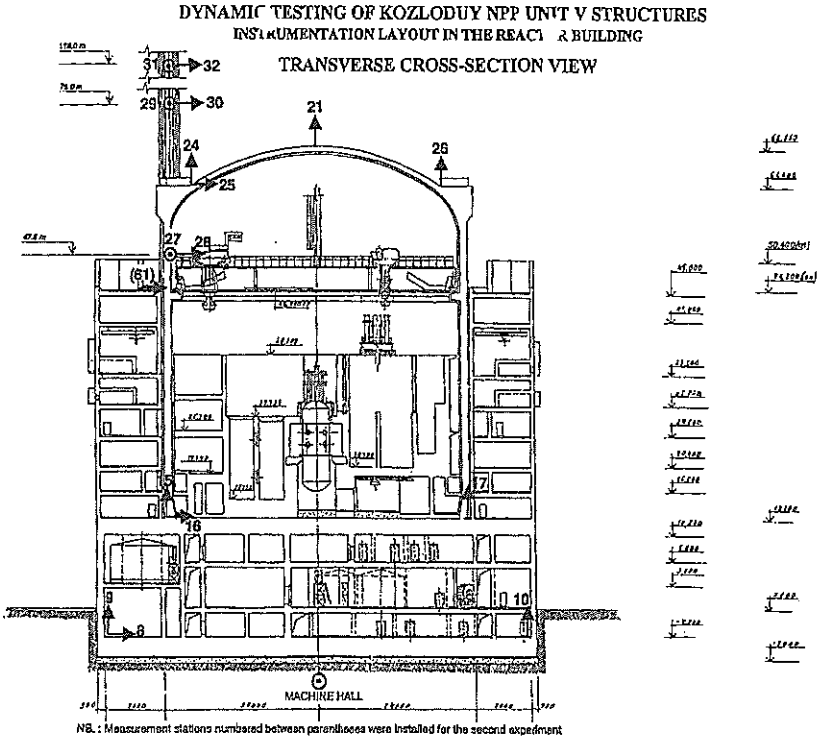

TABLE 7

Figure 1 Transversal cross-section view of the Kozloduy unit 5 reactor building

4 IMPEDANCE FUNCTIONS

The best estimate low strain soil properties of the site will be taken as the basis for soil-structure interaction analysis. The soil structure interaction action analysis was carried out with SASSI program [1] and the aim was to determine the impedances of the reactor building foundation. Impedances used in Nastran calculations are given as functions of frequency. These functions have been calculated from the formula $K + i\omega D = 1/(f + ig)$ in which f and g are real- and imaginary parts of the vibration amplitude corresponding to the impedance to be calculated. Precisely taking above equation is matrix equation, but in this case an approximation has been made and the impedances have been calculated separately. Torsion impedance has been assumed to be equal to rotational impedances about horizontal longitudinal and horizontal transversal axes. Subsequent verification calculation has indicated that this has not caused significant error. In the Nastran model impedances are distributed to eight springs and dashpots thus, that five on the slabs edges take care of moments and three in the middle area of the slab satisfy the translational impedances in longitudinal, transversal and vertical directions. Baseplate has been assumed to be rigid and massless. In the following figures the horizontal stiffness and damping impedance functions for Kozloduy unit 5 reactor building are depicted.

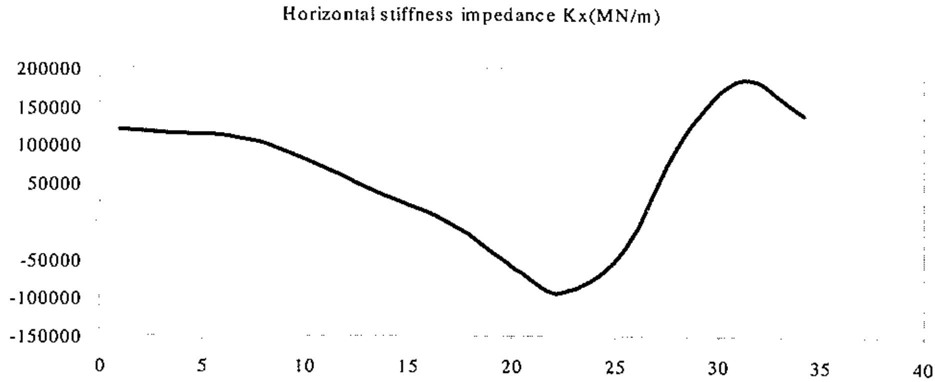

Figure 2 Horizontal stiffness impedance; argument axis is frequency in Hz

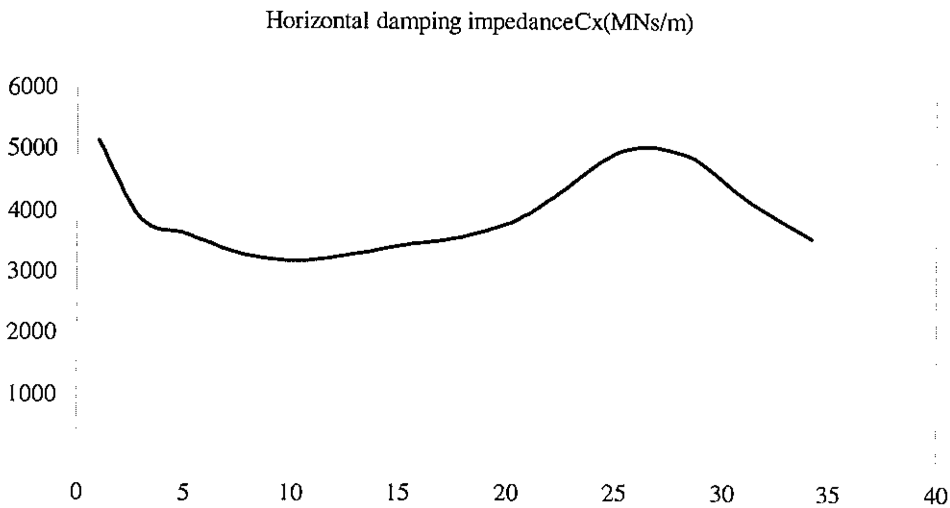

Figure 3 Horizontal damping impedance; argument axis is frequency in Hz

5 STRUCTURAL MODELLING

The FEM model has been developed with the aid of MSC/PATRAN pre-processing program. The model consist of 3000 nodal points, 4800 four node shell elements, 22 beam elements, 11 spring elements and 18 000 degrees of freedom. The mass of the structural model is 260 gigagrams. The Kozloduy model was reasonably regular. Its foot print was a perfect square with the side length of 66 meters and it was also nearly axisymmetric. The part below the elevation +13.2 was rectangular in geometry and above this elevation the containment building had cylindrical geometry and the envelope building had rectangular geometry. There was no structural connections between the containment and the envelope building and above the elevation +13.2 the model branched in two independent parts. The modelling principle for heavy components inside the structural model was that their masses were included in the model but the flexibility of their supports was neglected and they were rigidly connected to structures. The plot of the finite element model is presented next

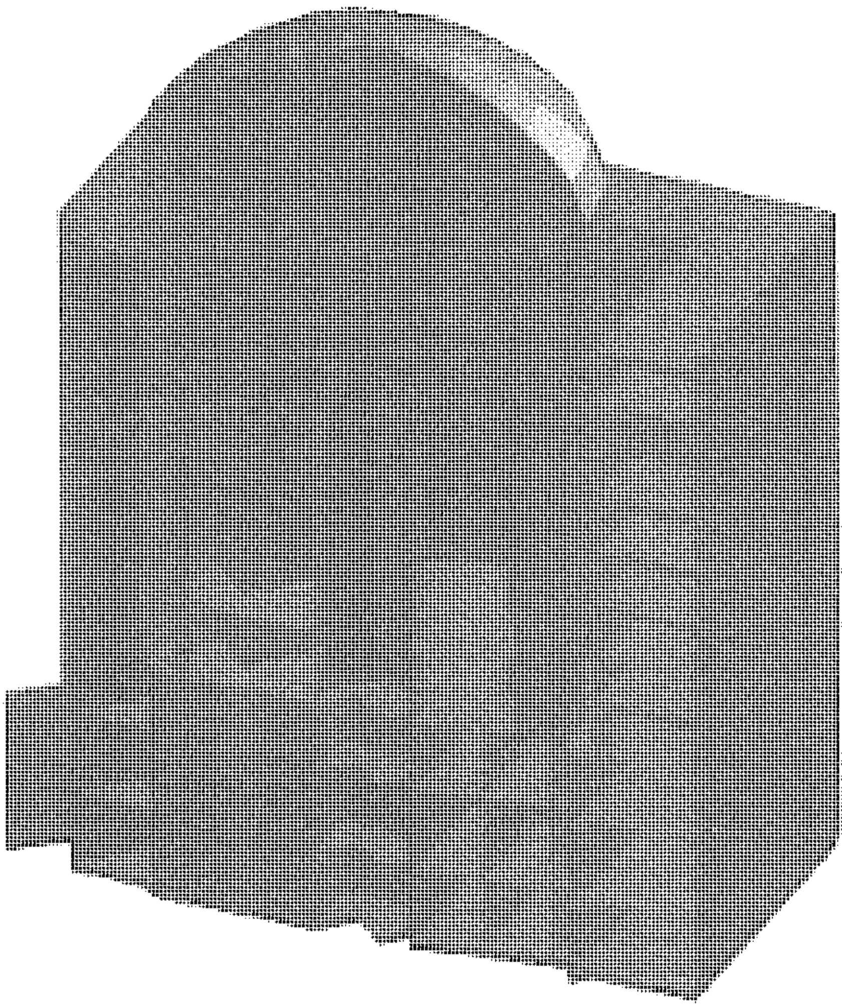

Figure 4 Isometric shaded view of the interior of the Kozloduy reactor building model

6 RESULTS OF THE STRUCTURAL RESPONSE ANALYSIS

The response results are presented in the form of time histories and response spectra. Most of the time histories are velocity time histories because the velocity was chosen as the primary response variable. The reason for this was that the primary response variable in measured responses was also velocity. For points p27 and p28 the measured response was in accelerations. In the following figures the response time histories and spectra are presented

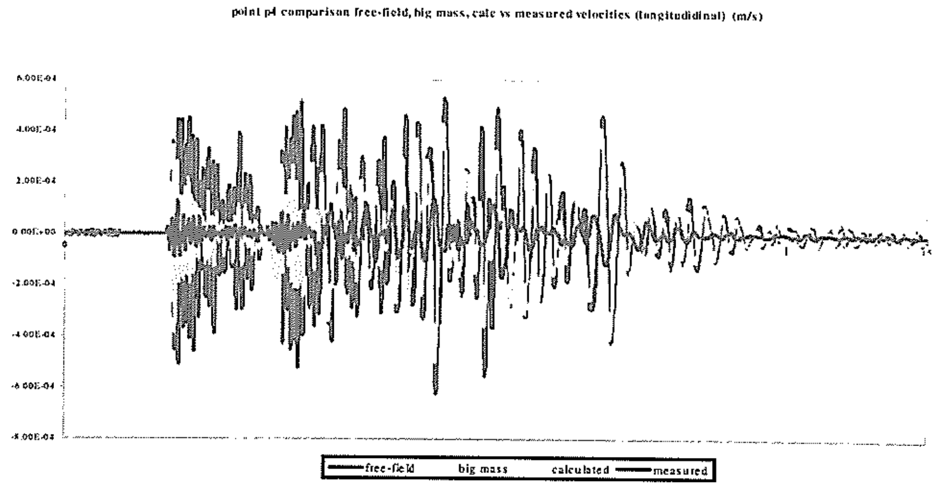

Figure 5 Calculated and measured velocity response at base slab elevation

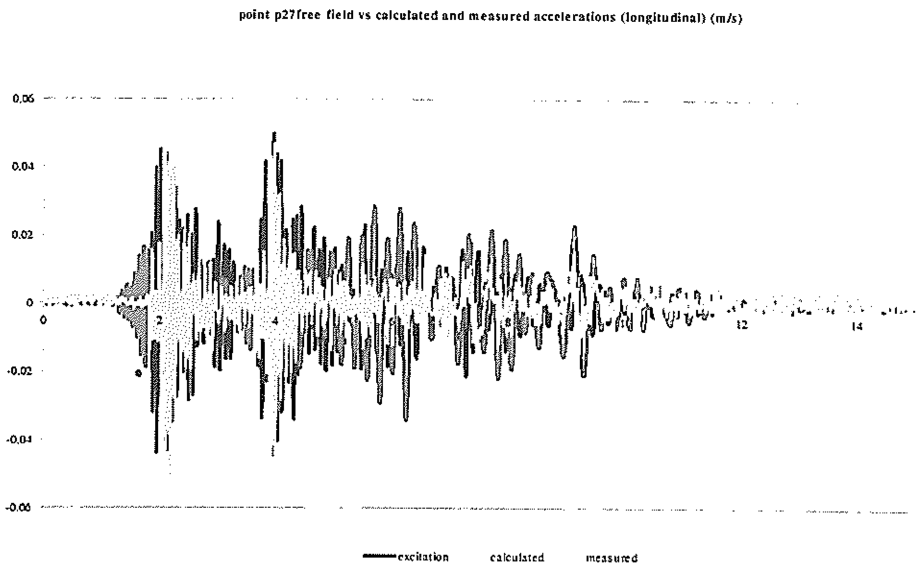

Figure 6 Calculated and measured acceleration response at polar crane elevation

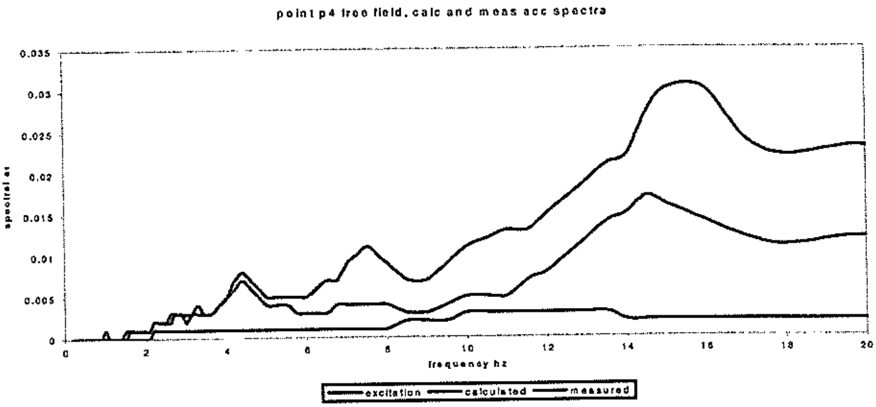

Figure 7 Calculated and measured acceleration response spectra at base slab elevation

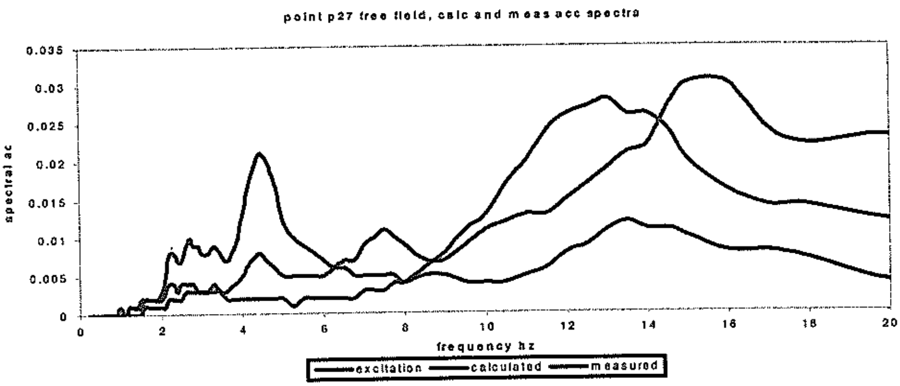

Figure 8 Calculated and measured acceleration response spectra at polar crane elevation

7 CONCLUSION

It seems to warranted to state that the used theory works satisfactorily for zero period response and reasonably for high frequency response. The differences between calculated and measured responses for these frequencies can be explained by the parameter variations within the adopted models. If the deconvolution and embedment are taken into account and if the soil internal damping and stiffness parameters are varied in reasonably limits it is possible to find a set of parameters that produce the measured response with acceptable accuracy for the purposes of engineering calculations.

To support this statement we show the effect of the deconvolution to the amplification profiles for zero period in the following figure

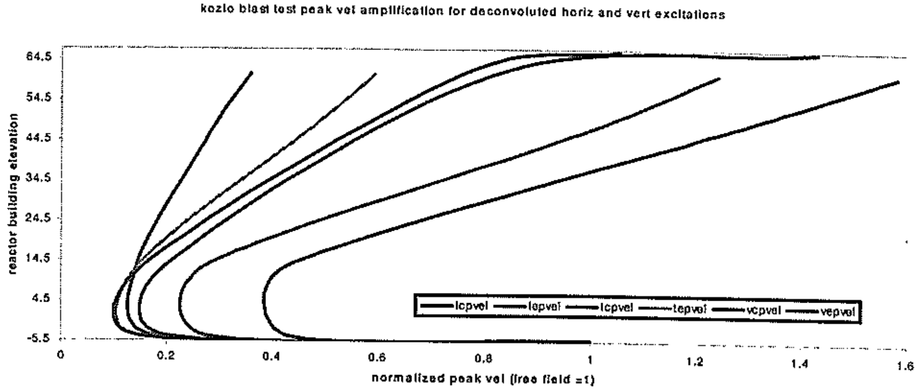

Figure 9 Velocity amplification profiles for longitudinal, transversal and vertical direction

In Figure 9 the two curves in right are the calculated and measured longitudinal responses. As can be seen the curves are similar in shape but the calculation overestimates the response. The two curves in the middle of the plot are vertical measured and calculated responses and for this component the analysis agrees best with measurements. The two curves in the left of the plot are the transversal responses. For this component the analysis underestimates the response for elevations higher than the containment floor elevation.

8 REFERENCES

[1] Lysmer J., & al. 1988. SASSI-A System for Analysis of Soil-Structure Interaction. *University of California*, Berkeley, California 1988.