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KW2/10

Blast excitation response of Kozloduy unit 5 VVER-1000 NPP reactor building

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ABSTRACT

The study is a part of the IAEA coordinated research program "Becnhmark study for the Seismic Analysis and Testing of VVER Type NPPs". Current paper reports a part consisting of blind round-robin analysis of the response of Kozloduy unit 5 VVER-1000 NPP reactor building for blast excitation load. The SSI-response of the reactor building is assessed directly. The structural model is analyzed by mode superposition method in frequency domain. Results are acceleration histories in time domain for selected points.

1. INTRODUCTION

The IAEA benchmark is a coordinated research program started in 1993. It has full participants of over 20 countries and contributors from 16 countries. The prototype plants are Kozloduy for VVER-1000 reactors and Paks for VVER-440/213 reactors. The objectives of the program are enhancement of safety of VVER reactors and transfer of technology and knowhow.

The Kozloduy plant has two VVER-1000 reactors. Unit 5 has been in operation since 1986 and unit 6 since 1991. In the original seismic design of units 5 an 6 a generic value of 0.1 g of peak ground acceleration (pga) was used. It has been revised since and the new site specific input distinguishes between far-field and near-field effects. The far-field pga is 0.2g and the near-field pga is 0.25g.

2. BLAST TESTS

The blast tests took place in July 1996. The number of the measuring positions were 16 and they were located in various elevations as follows: on the basemat (level -4.20) points 4,5,6; on the containment base slab (level +13.20) points 11, 12, 16; on the containment springline (level +61.00) points 18, 19, 23; on the containment apex (level +.66.55) point 21; on lower platform of chimney (level +78.00) points 28, 29; at medium platform of the chimney (level +118.00) points 31,32 and at the top of the envelope building (level +47.50) points 27, 28.

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

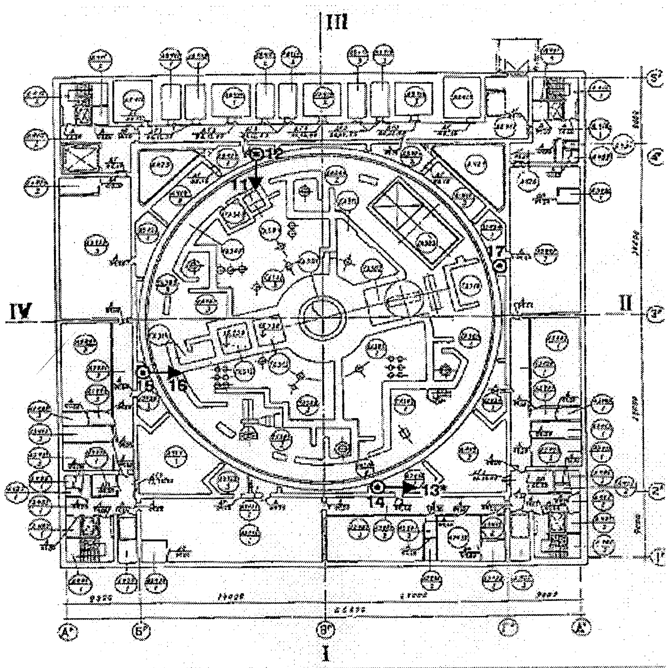

Figure 1 The containment base slab at elevation +13.20

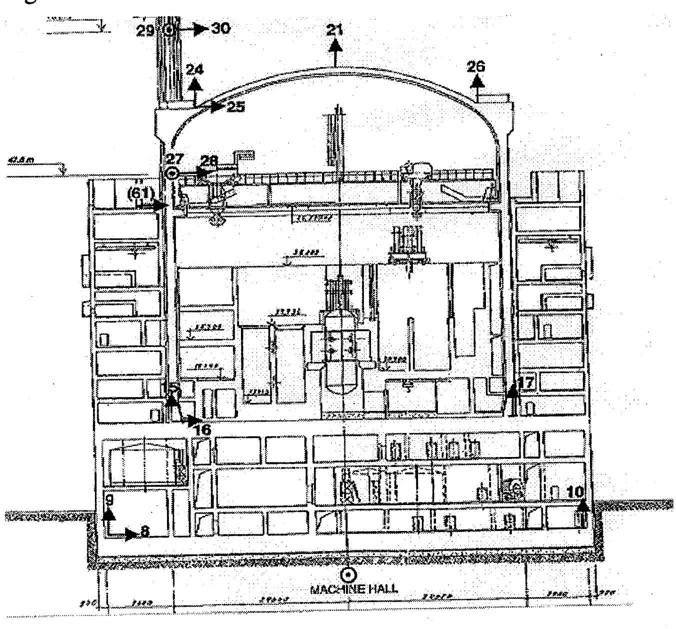

Figure 2 The reactor building cross-section

The free- field measurement location of the blast test was situated in the 139 m distance from the reactor building center of the unit 5. As in the case of Paks experiment [1], the free field excitation was measured through seismometers and the original measurements are velocity values, the acceleration values have been developed through a derivative of the recorded velocities. The use of the original velocity data is recommended where possible. In the following Figures the free-field blast accelerations and corresponding response spectra are depicted. The units for accelerations are m/s^2 and time is in seconds and frequency in Hz.

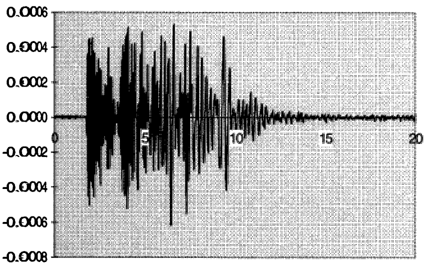

Figure 3 Longitudinal acceleration history

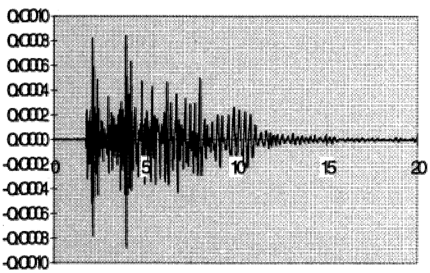

Figure 4 Transversal acceleration history

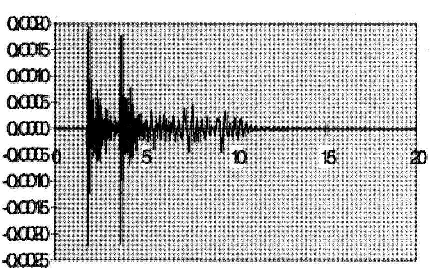

Figure 5 Vertical acceleration history

The corresponding response spectra are plotted in Figures 6, 7 and 8. The damping ratio for all response spectra is 5 per cent.

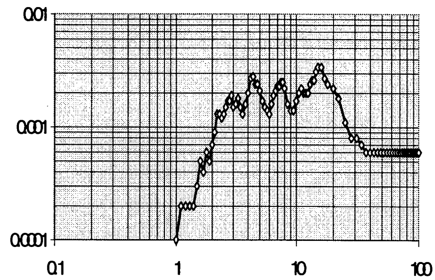

Figure 6 Longitudinal response spectrum

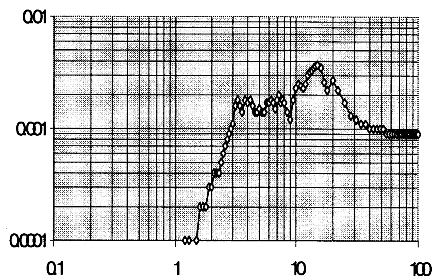

Figure 7 Transversal response spectrum

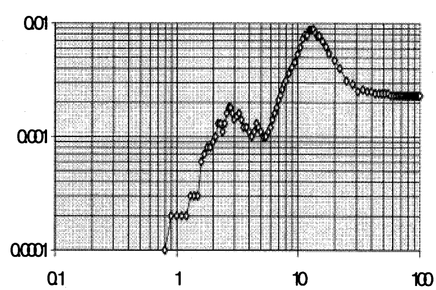

Figure 8 Vertical response spectrum

As can be seen from the time histories the blast test has been a double charge test with about two seconds interval.

3. STRUCTURAL MODELING

The Kozloduy unit 5 structures and the response of the reactor building has been studied already earlier during the bechmark program. Studies of Asfura [2], Ambriashvili [3] and Halbritter [4] are noteworthy. 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 plot of the finite element model is presented in Figure 9.

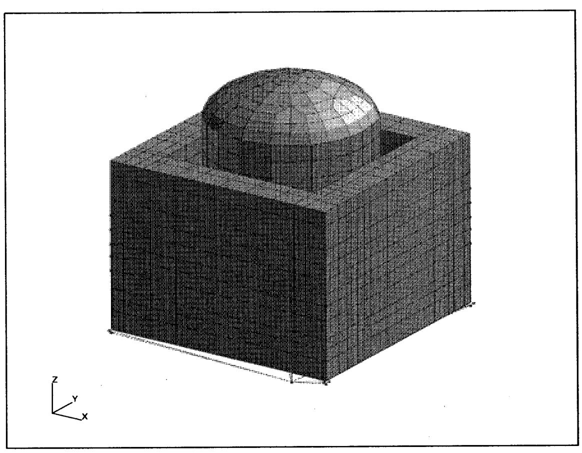

Figure 9 The FEM model of the reactor building

4. SOIL STRUCTURE INTERACTION

The best estimate low strain soil properties of the site will be taken as the basis for soil-structure interaction analysis. The layering of the soil is given in Table 1.

Shear wave velocity m/s	Density kg/m^3	Poisson's ratio	Thickness m
490	1800	0.40	2.00
380	2300	0.36	4.00
500	2000	0.45	2.80
600	2270	0.45	1.70
680	1900	0.45	10.00

Table 1 The properties of soil layers beneath the reactor building

The horizontal and rocking soil impedance's were calculated on the basis of the above layering using the SASSI program. The resulting frequency dependent impedance's are depicted in Figures 10- 13.

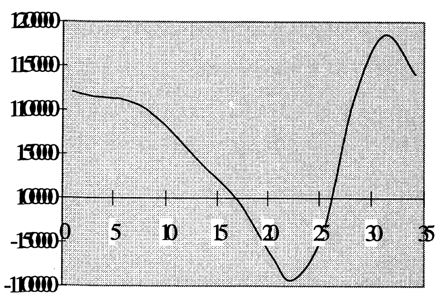

Figure 10 Horizontal foundation stiffness

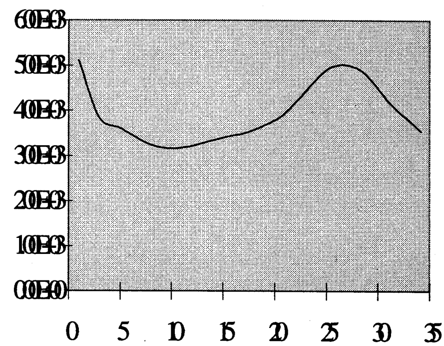

Figure 12 Horizontal foundation damping

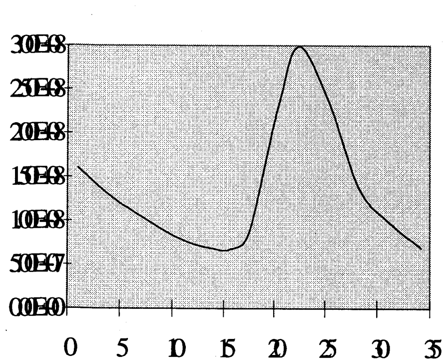

Figure 11 Rocking foundation stiffness

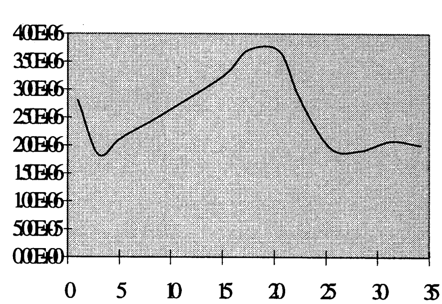

Figure 13 Rocking foundation damping

The units of translational stiffnesses are meganewtons per meter and the units of rotational stiffnesses are meganewton meters per rad. The units of translational dampings are MN s/m and the units of rotational dampings are MN ms /rad.

The impedances were calculated in SASSI assuming that square foundation slab of the reactor building is infinitely stiff and massless. The internal damping coefficient for the foundation soil was assumed to be 2 per cents from critical.

The calculated impedance's will be transferred to the structural analysis program MSC/NASTRAN in the form of complex frequency dependent springs. The solution in frequency domain in NASTRAN is carried out in direct method or modal method. The modal method is iterative and in the first phase the normal modes of the structure are calculated using the average values for frequency dependent stiffnesses. In the second phase the frequency dependency is taken into account and the Fourier components of the responses are solved for specified frequencies. The SASSI soil-structure interaction methodology has been described in reference [5].

5. MODE EXTRACTION ANALYSIS

The mode extraction analysis was made with average values of the foundtaion impedances. In the Table 2 the first six modal frequencies are tabulated.

Mode number	Frequency Hz
1	2.20
2	2.20
3	3.43
4	3.81
5	4.35
6	4.35

6. PRELIMINARY RESPONSE OF THE BASE SLAB

The effect of the blast excitation was assessed preliminarily by studying one degree of freedom system which had the same frequency as the lowest frequency calculated in section 5. The excitation to this system was the longitudinal component of the blast excitation scaled by the factor of 100 000 so that maximum acceleration amplitude was 0.6g. This scaling ensured that the response quantities were not excessively small and because linear system was investigated the scaling does not have any effect on the response amplification. The tentative value of the damping was taken to be 5 % of critical.

With this simple model some pre- analysis insight to the problem was obtained. The response of the one degree of freedom model to the longitudinal, horizontal component of blast excitation is depicted in Figure 11.

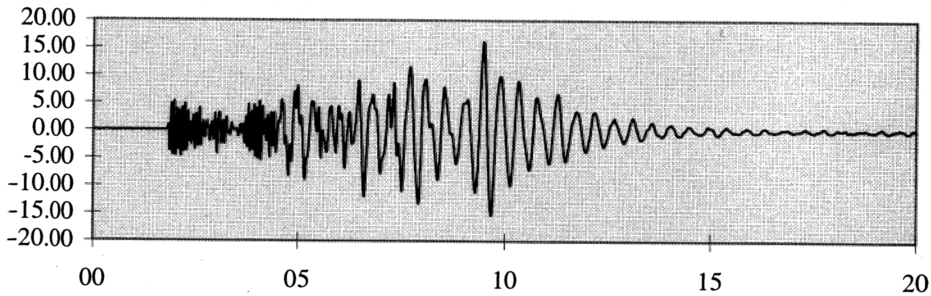

Figure 14 The one degree freedom system approximation of the base response amplification.

The units in Figure 14 meters and seconds. There are three phases in the motion depicted in Figure 14. First five seconds follow the excitation without any visible amplification. During the following five seconds the amplification sets in and reaches its maximum value at ten seconds where the level of excitation is tripled. After that point the excitation dies away and the damping causes the response to vanish in the remaining ten seconds. The result of Figure 14 gives reason to expect that soil-structure interaction in Kozloduy soil conditions amplifies the blast excitation. This can also be expected by inspecting the response spectra in Figure 6 where the amplification effect begins at the frequency of 2 Hz. The frequency of the one degree of freedom model was 2.2 Hz.

7. CONCLUSION

The developed model had the lowest frequencies around 2 Hz when the average values of foundation impedance's were used. The foundation impedance's were calculated assuming that the foundation slab is infinitely rigid and massless. The foundation impedance's were developed using the SASSI methodology. The response spectra of the blast excitation acceleration components were also developed. Studying the frequency content of horizontal excitation and the expected lowest eigenfrequencies of the structural model it is to be expected that the motion is amplified in the horizontal direction. In vertical direction the response in the structure is expected to be less than the excitation motion.

8. REFERENCES

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