

FLOOR RESPONSE SPECTRA

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Introduction.

The seismic safety evaluation of the equipment in industrial buildings and particularly in nuclear power plants (NPP) requires generation of design floor response spectra and floor time histories representing the input for analysis of components which are not modelled together with the supporting structure. Floor response spectra can be obtained on the base of structure response to design base ground motion. The generation of floor response spectra for Units 1 and 2 of NPP "Kozloduy" is discussed shortly in the report.

Seismic input, soil-structure interaction and modelling of building structure.

The design response spectrum (used for the three input motion components) is applied at the free-field surface, the maximum horizontal acceleration being $0.2g$ and the vertical – $0.1g$. This spectrum has a very long part of maximum spectral accelerations (up to period of 1.7 s). The "control motion" is represented not only by the design spectrum but also by generated acceleration time histories compatible to that spectrum.

To evaluate the soil-structure interaction, investigations are carried out with two-dimensional models (Kostov, 1992) in transversal and longitudinal directions. Because of the peculiarities of the local ground conditions of NPP "Kozloduy" site (at a depth of 222 m the shear wave velocity is less than 700 m/s and existence of softer layers below stiffer ones) different variants of "free field column" are studied in order

to justify the depth of the soil-structure model (finally 48 m depth is accepted). Finite element method of analysis and computer codes FLUSH and PLUSH are used. Part of the model is shown in Fig.1.

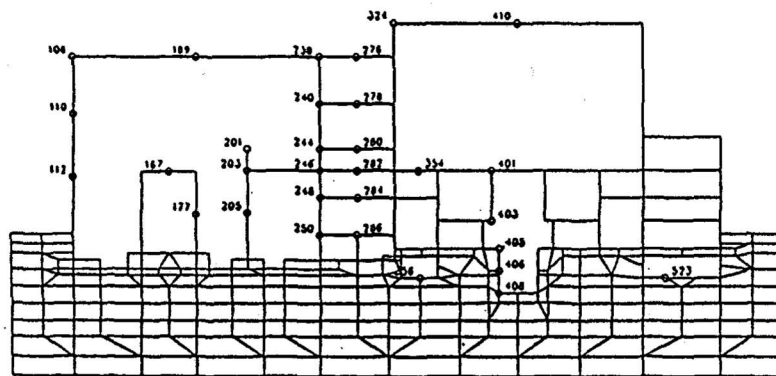


Fig. 1. Cross section of 2-D model of the soil-structure system.



Fig. 2. Fourth mode of vibration of the soil-structure system.

Nodal points at which the response spectra are computed are marked also. Three variants of soil characteristics are included in the computations. The variation of shear modulus and damping in function of effective shear strain is taken into consideration by equivalent linearization procedure. The 2D modelling of the soil-structure system is given in details in (Kostov, 1992). The structure is modelled in two variants in transversal direction: with elastic connections between girders and columns in intermediate part of the building and with rigid connections. Natural periods and modes

of vibrations of the structure only and then of the soil-structure system are computed. Fourth mode of vibration of the system is shown in Fig. 2.

The floor response spectra are generated by direct method (the control motion is represented by the design response spectrum) but in order to determine the confidence level (the level of conservatism) for different points of the structure the floor spectra are computed also applying generated time histories as input motion. The probability of not exceeding of 97% is accepted. The acceleration response spectra at different points of the foundation level as well as their envelopes are computed for horizontal and vertical motion. Those spectra are used as input motion for computations of the structure.

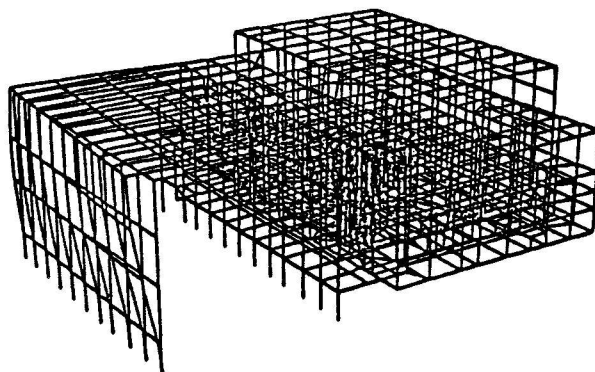


Fig. 3. First mode of vibration of 3-D model of the main structure.

The structure of Units 1 and 2 of NPP "Kozloduy" is a complex spatial structural system composed of two parts completely different in respect to their stiffness – turbine hall and reactor building. They are connected by an intermediate building without a separation joint. A temperature expansion joint exists in the middle of turbine hall (in longitudinal direction). The irregularities in height and plan of the structure require the spatial behaviour to be analyzed. Only 3D model can show the rotational effects arising as a result of seismic excitation. Three separate models are analyzed – the independent part of the turbine hall (up to the separation joint); the main part, consisting of reactor building, turbine hall, intermediate building, ventilation center and control rooms; the whole structure representing combination of the previous two models. In such a way torsional effects as well as the role of separation joint could be established. All 3D models are described in details in (Kostov, 1993). The full model consists of 1363 nodes, connected in 1090 beam elements and 1371 rectangular elements. Cross-section of the model through reactor building is shown in Fig. 3. Natural frequencies and modes of vibration of the three spatial models are analyzed using

STARDYNE computer code. First mode of vibration of the second model is given in Fig. 4. First, fourth and sixteenth modes of vibration of the full model are shown in Fig. 5, 6 and 7.

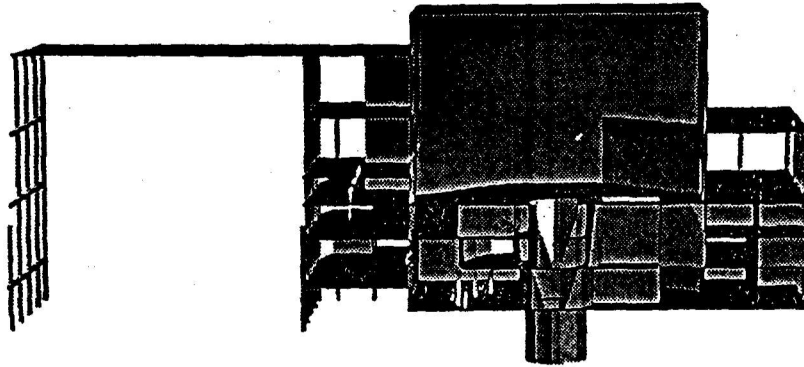


Fig. 4. 3-D Model, cross section through reactor building.

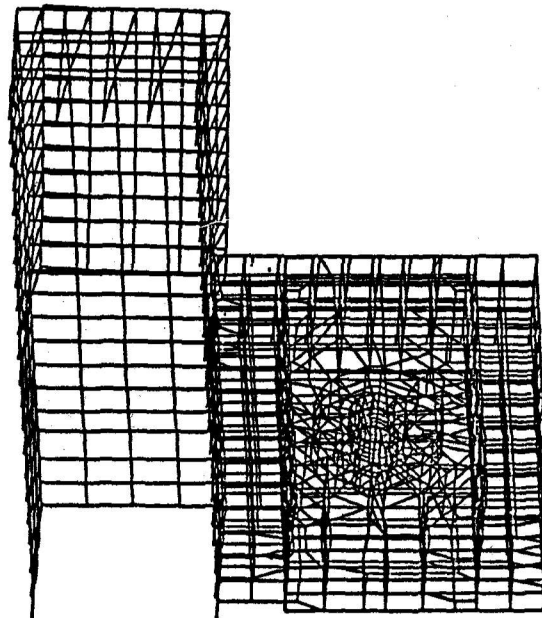


Fig. 5. 3-D model, first mode of vibration.

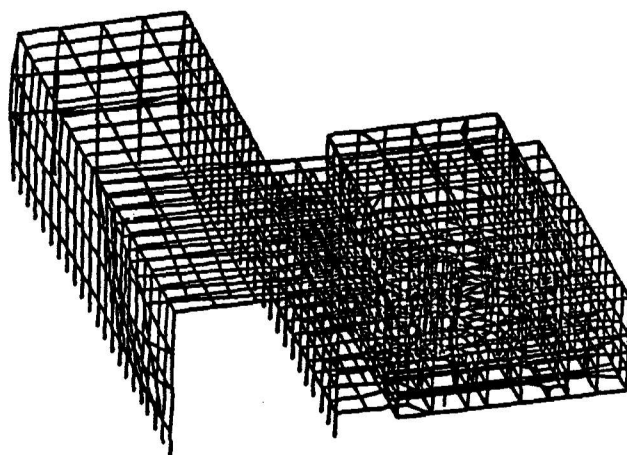


Fig. 6. 3-D model, 4-th mode of vibration.

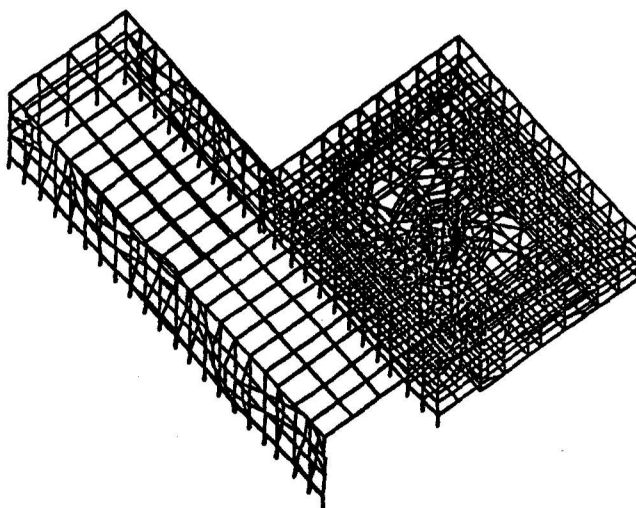


Fig. 7. 3-D model, 16-th mode of vibration.

Processing of floor response spectra.

By direct method for all 2D models (in transversal and longitudinal directions) acceleration response spectra at nodal points shown in Fig.1 are computed for horizontal and vertical motions, due to three components input motion applying the SRSS

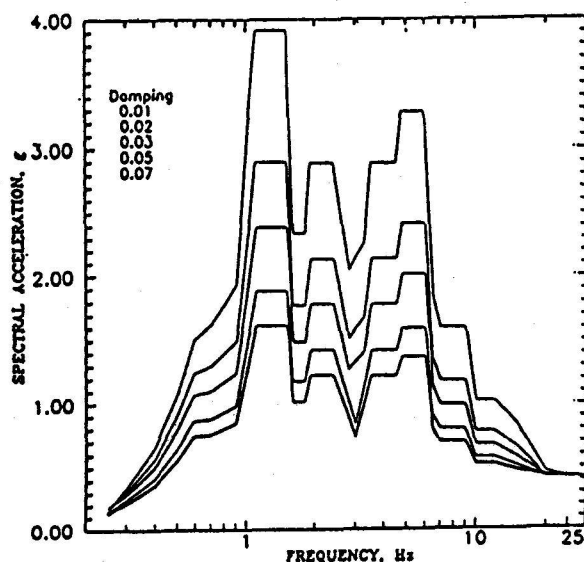


Fig. 8. Acceleration floor response at point 276.

procedure. The final results are the envelope spectra for different damping – 1, 2, 3, 5 and 7 % of critical damping. Then the spectra are smoothed and broadened using the 15 % criterion according to (U.S.NRC, 1978).

The spatial dynamic analysis shows that the intermediate part of the building is subjected to torsional motion. Following the requirements of IAEA and U.S.NRC (1989, 1991) the rotational effects are taken into account by 25% increasing of horizontal response spectra at all points of the girders in that part of the model. This correction is established comparing the accelerations in different points obtained by 2D and 3D models. The final acceleration floor response spectra at point 276 is shown in Fig. 8. The response spectra for vertical motion at points along the columns and in the middle of girders (points 238 and 276, 240 and 278, etc, Fig. 1) prove the existence of considerable vertical components of the motion in the girders.

On the basis of dynamic analysis performed for structures of Units 1 and 2 recommendations for upgrading of buildings could be done.

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