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Seismic Response Analysis of Nuclear Island Buildings in LNNP Unit 1

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ABSTRACT

The paper studies the seismic response characteristics of nuclear island buildings in Leningrad Nuclear Power Plant unit 1. The excitation in the free field is assumed to be seismic ground motion and will be defined by the acceleration response spectrum described in the reference [1]. The spectral shape to be used to define this motion corresponds to a median (50 percentile) spectrum developed for soil sites. For the Leningrad plant, the horizontal peak ground acceleration will be assumed equal to 0.1g. The vertical spectrum will be assumed equal to 2/3 of the horizontal spectrum. In order to form the analysis model used in the seismic response calculation of the seismic response of the nuclear island buildings of LNNP unit one the finite element model for reactor building has been merged with electrical building and turbine building models to form the joint structural model for nuclear island buildings. The floor response spectra for the seven floor elevations of the nuclear island buildings are developed. The spatial location of the response spectra generation in the plane of the floors was the shear center of the respective floor slab. The spectra were generated in three directions for x-, y-, and z-directions and for the damping ratios of 0.5%, 2%, 5%, 7% and 15.

KEY WORDS: seismic response characteristics, excitation, free field, ground motion, acceleration response spectrum, soil sites, peak ground acceleration, seismic response, nuclear island buildings, finite element model, joint structural model, floor response spectra, shear center, floor slab, damping ratios.

INTRODUCTION

This report describes the seismic response analysis of the electrical building (de-aerator building) and turrbine building of LNPP unit one. The method of the analysis is direct integration of the dynamic governing equation of the structural finite element model. The model is developed to include all buildings of the nuclear island of LNNP unit one, namely, reactor building, electrical building and turbine building. In this task the floor response spectra for the seven floor elevations of electrical building and four floor elevations of turbine building are developed. The spectra were generated for elevations –6.00, 0.00, +7.00, +14.4, +19.2, +30.0 and +37.0 for the electrical building and for the elevations –6.00, +0.00, +12.00 and +30.00 for turbine building. The spatial location of the generation in the plane of the floors was the shear center of the respective floor slab. The spectra were generated in three directions for x-, y-, and z-directions and for the damping ratios of 0.5%, 2%, 5%, 7% and 15%. .

THE EVALUATION OF SEISMIC GROUND MOTION

Generic ground motion for LNNP site

To demonstrate the uncertainty in the development of the ground motion at investigated plant site two different ground motiios are considered in evaluating the seismic fragility od the five selected heavy components listed in section 1. The first seismic ground motion will be defined by the acceleration response spectrum described in the reference [ ]. The spectral shape to be used to define this motion corresponds to a median (50 percentile) spectrum developed for soil sites. For the Leningrad plant, the horizontal peak ground acceleration will be assumed equal to 0.1g. The vertical spectrum will be assumed equal to 2/3 of the horizontal spectrum. The horizontal spectrum is shown in Figure 1.

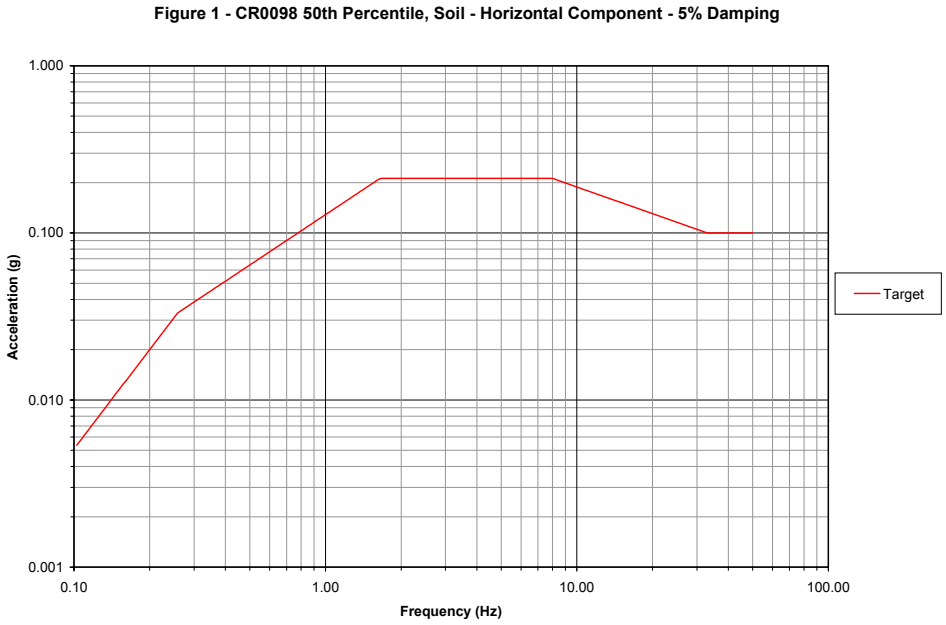

Figure 1 CR0098 50th Percentile, free-field horizontal component, 5% damping

Three independent acceleration time histories were developed to match the horizontal and vertical target response spectra. The characteristics of these time histories are as follows: 1)Total duration = 20 seconds; 2)Time step = 0.01 seconds. Figure 2 shows the trace of the first horizontal component of the set of artificial time histories (2 horizontal components, 1 vertical component).

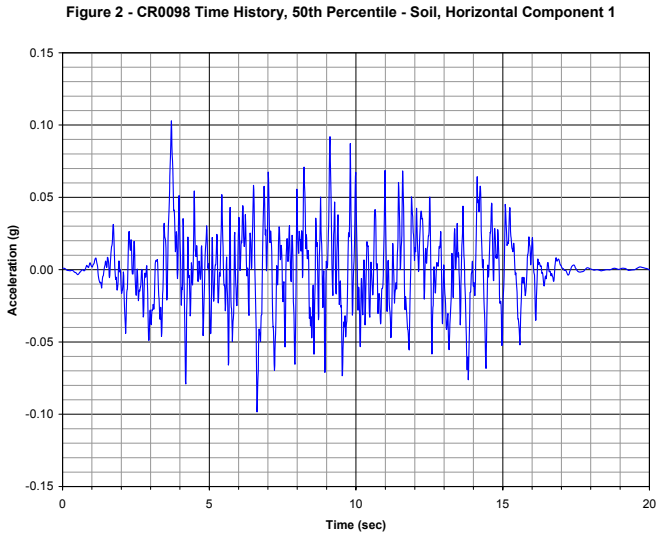

Figure 2 CR0098 acceleration time history, 50th Percentile-free field, horizontal component 1

Site specific ground motion in the LNNP site

In the soil structure, seismic waves can be amplified as they propagate owing to a variety of factors: contrasting impedance between the bedrock and superficial layers due to the conservation of energy; resonance phenomena if the dominant period of the incident wave is close to the fundamental period of the superficial layer; and topographical effects [2]. This modification of ground motion is often called amplification, but also site effect.

The flat topography and geological interpretation [3] of the southern coast of the Gulf of Finland indicate that the bedrock is a horizontal plane and the superficial soil layers are horizontally stratified. The lack of topographical effects enables to present the soil characteristics by a column. A given soil column is assumed to be composed of a number of uniform soil layers of arbitrary thickness, each with linear soil properties.

The site effects of the Sosnovy Bor were analysed with the program CARES [4] . The soil characteristics of the NPP site are presented in Table 2. The total thickness of the soil column is 180 m. The damping ratio used in the analysis is the average of D_p and D_s. The basement level of the power plant is at - 6 m, i.e. at the top of the layer number 3.

Table 1 Soil characteristics of the Sosnovy Bor site. H = thickness of the layer; V_p and V_s = P- and S-wave velocity; ρ = density; D_p and D_s = damping factors for P- and S-waves; μ=shear modulus.

Layer	h (m)	V_p (m/s)	V_s (m/s)	ρ (g/cm^3)	D_p	D_s	μ (kg/ms^2)
1	2	400	180	1.7	0.55	0.6	5.51E+07
2	4	1100	250	1.8	0.5	0.6	1.13E+08
3	4	1500	350	1.9	0.4	0.5	2.33E+08
4	20	2000	350	2.2	0.15	0.4	2.70E+08
5	30	2200	450	2.3	0.1	0.35	4.66E+08
6	120	2500	650	2.4	0.05	0.05	1.01E+09

The objective of the soil structure analysis is to determine the acceleration response spectra at the basement of the reactor building, when a specified acceleration time history (accelerogram) is the input at the basement (bedrock) of the soil column. The excitation at the bottom of the soil column is an artificial acceleration time history compatible to the design spectrum.

Seismic waves propagating through the layered soil are simulated as shear waves travelling vertically through a soil idealised as horizontally bedded layers. The Fourier components of the motion at any depth of the profile can be obtained through a de-convolution/convolution analysis. The acceleration time history and response spectrum at the basement of the building are presented in Figure 3 and Figure 4. The estimated peak ground acceleration at the basement level is 0.14 g and the acceleration value at the frequency of 5 Hz is 0.7g. The excitation occurs mainly between depths 180-60 m, i.e. in the 120 m thick lowermost layer. Generally, the layer above increases the amplification effect, but around 20 Hz the amplitudes are damped. From the top of the layer 4 to the ground surface (the uppermost ten meters) the response spectra are practically equal.

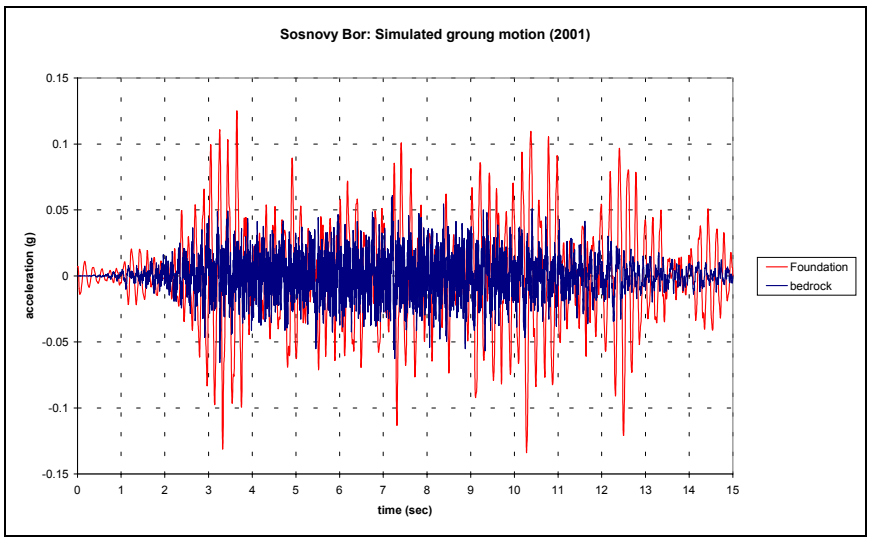

Figure 3 Original and de-convoluted accelerogram at Sosnovy Bor site.

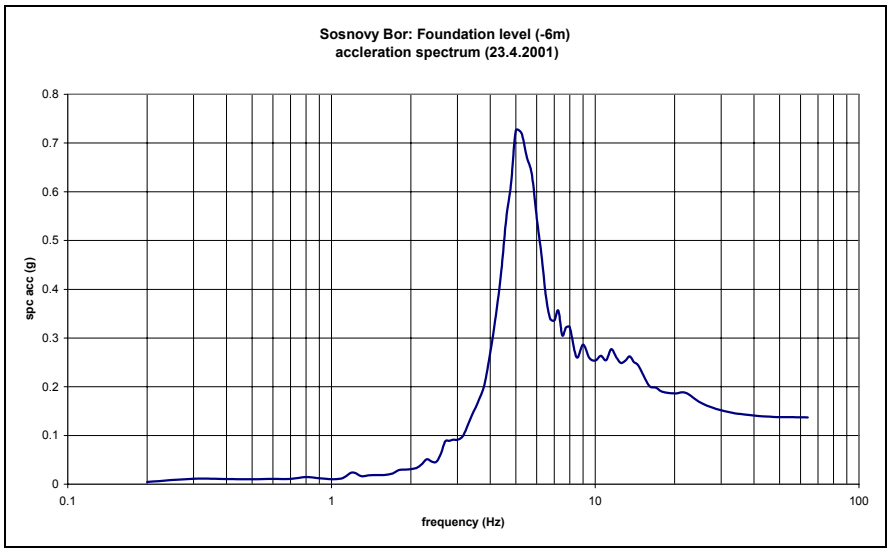

Figure 4 Computed acceleration response spectrum at the basement level of the building

FINITE ELEMENT MODELLING

Modelling of the electrical building

Modelling of the electrical building has been carried out by 3-D finite elements. Elements used in modelling were rectangular shell elements with 4 nodes and straight beam elements with standard I-shape (2 nodes). The coordinate system used was standard rectangular XYZ-coordinate system. Shell elements were modelled on middle surfaces of wall and elevations and their thickness was given as an element property. Beam elements were modelled on curve in one dimension and their shape and dimensions were likewise determined as element property. Each node in the model has six degrees of freedom, translations in the X-,Y- and Z-directions and rotations around X-, Y- and Z- axes. Materials used in electrical building are concrete and steel. Modulus of elasticity of concrete is 30 000 N/mm^2 and Poisson's ratio is 0.2. For steel the modulus of elasticity is 200 000 N/mm^2 and Poisson's ratio 0.3. The density for concrete is 2500 kg/m^3 and for steel 7800 kg/m^3. These values are best estimate values used for obtaining the best estimate values for in-structure response.

Turbine building modelling

The turbine building consists of steel frame, three elevations in cast-in-situ concrete, panel walls of roof panels of pre-cast concrete. The overall dimensions of the building are 210x51x36 meters. and the location of the building is adjoining to electrical building. The turbine building model was developed in four stages. First, the steel skeleton of the building was set up by modeling one typical steel frame. The typical steel frame consists of two columns and of the roof girder truss. The typical frame was then copied 35 times to form the skeleton structure of the building. Four spans of the building skeleton were braced in longitudinal direction with steel stiffening trusses to provide for the horizontal stiffness of the building frame. The third phase base of the model development set up the foundation slab, the intermediate slab at elevation +0.00 and the main operation deck at elevation +12.00. The last and fourth step in the model development described the outer walls and the roof panels.

Joint model of all buildings of LNNP unit 1 nuclear island

In order to form the analysis model used in the seismic response calculation of the electrical building and turbine building of LNNP unit 1 the finite element models for reactor building has been merged with electrical building and turbine building models to form the joint structural model for nuclear island buildings. The joint soil-structural model of the nuclear island buildings has been shown in Figure 5.

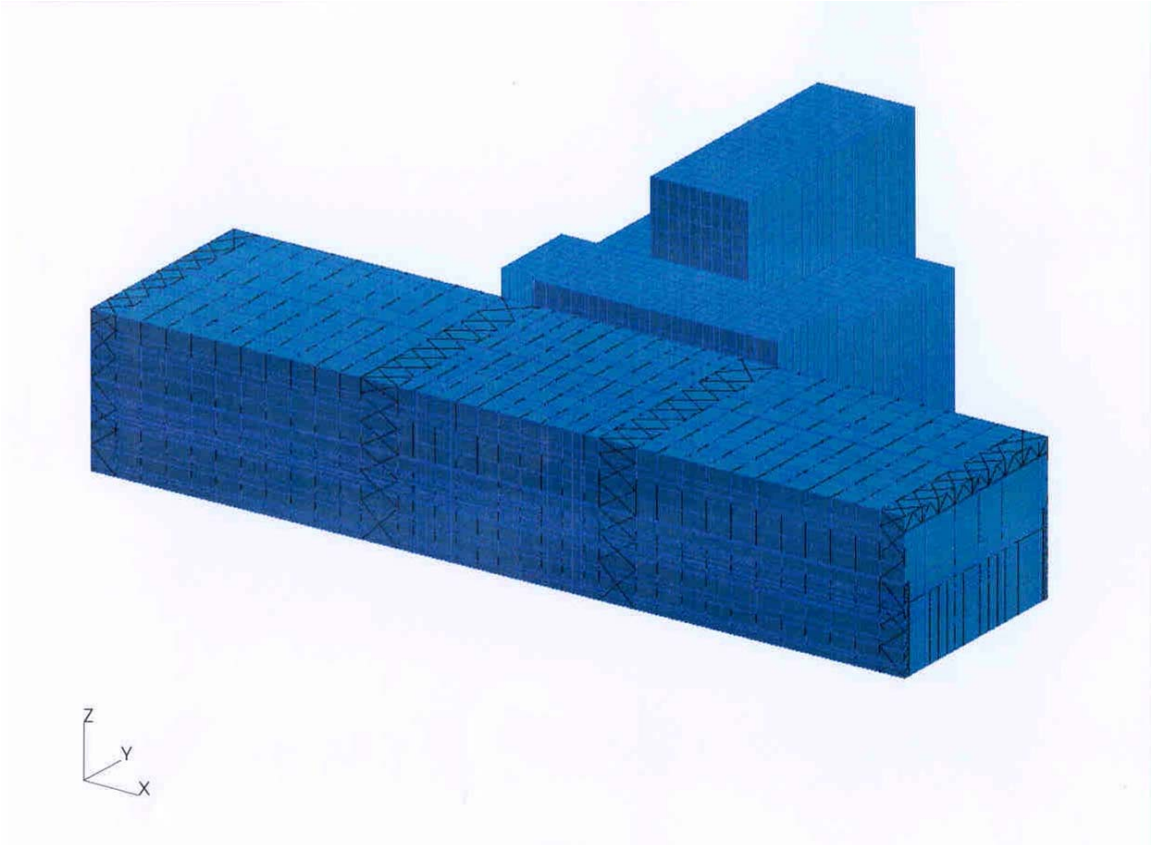

Figure 5 The joint structural model for nuclear island buildings

FLOOR RESPONSE SPECTRA FOR NUCLEAR ISLAND BUILDINGS

The floor response spectra for the seven floor elevations of electrical building and four floor elevations of turbine building are developed. The spectra were generated for elevations –6.00, 0.00, +7.00, +14.4, +19.2, +30.0 and +37.0 for the electrical building and for the elevations –6.00, +0.00, +12.00 and +30.00 for turbine building. The spatial location of the generation in the plane of the floors was the shear center of the respective floor slab. The spectra were generated in three directions for x-, y-, and z-directions and for the damping ratios of 0.5%, 2%, 5%, 7% and 15%. The acceleratin floor response spectra in m/s^2 for horizontal y-direction for turbine building elevation +12.00, for electrical building elevation +14.40 and for reactor building elevation 14.40 have been shown in Figures 6, 7 and 8.

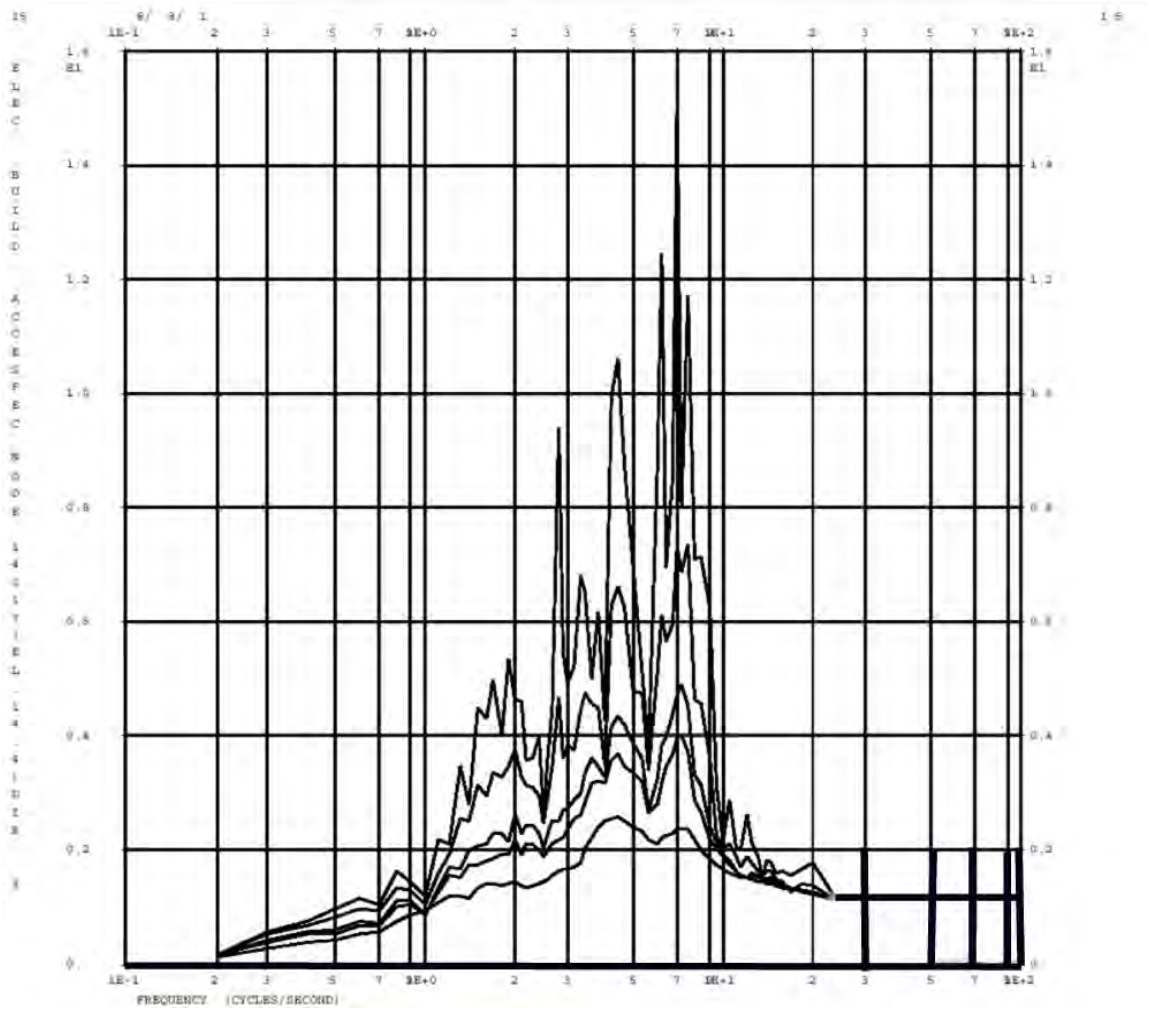

Figure 6 Floor response spectra for the electrical building at elevation +14.40 direction y

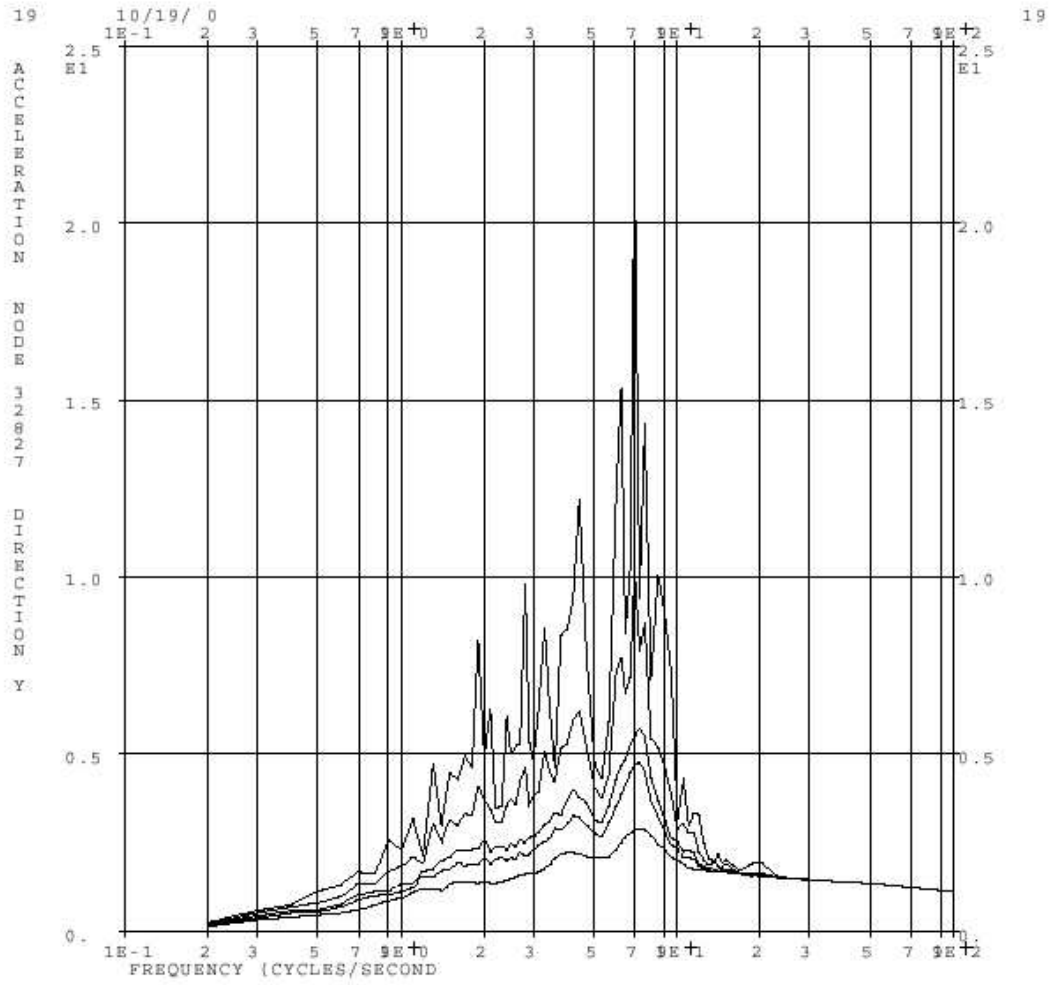

Figure 7 Floor response spectra for reactor building at elevation +14.40 direction y.

CONCLUSION

The point finite element model for reactor building, electrical (deaerator building) and turbine building of LNNP unit 1 is generated. The joint model is developed by merging the individual building models of the nuclear island buildings of LNNP unit 1. The floor response spectra of the electrical building, of the turbine building and of the reaktor building are generated using the joint finite element model for nuclear island and the ground motion defined in Subsection: „Generic ground motion for LNNP site".

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