Application of Optimization Program IOSO NM and ABAQUS at Civil Structures of NPP

V. Korotkov
Atomenergoproekt

I. Egorov and S. Kuptsov
Sigma technology

S. Ryzhov and K. Ilin
TESIS

Abstract: At the stage of NPP civil structure design for determination of stress-strain state (SSS) at static and dynamic loading ABAQUS is widely used [1]. Hereto the floor response spectra are determined for calculation of loadings on the equipment at special dynamic impacts (seismic, air shock wave, aircraft crash). In case if the obtained characteristics of SSS or spectral accelerations exceed maximum permissible values, designers take actions on strengthening the corresponding structural components.

It should be noted that real civil structures of NPP are rather complex structures. Numerous geometrical parameters, such as thickness of walls and floorings, geometrical characteristics of columns and beams create multiparameter system. In such systems decrease of the calculated values of SSS due to strengthening of some structural components can lead to increase in SSS values for the other structural components. Therefore, complicated and generally speaking non-system choice of structure geometry, realizing the "optimum" SSS, is made.

For system design of structures there exist the methods of the linear and nonlinear programming, allowing to calculate an optimum structure. In this paper the technology of optimization of the NPP civil structures has been applied, developed on the basis of ABAQUS and technologies of IOSO NM [2-4], a formula of the method and the results of calculations are given.

Use of such system approach to a choice of optimum parameters for calculation of response spectra has allowed twice as much to decrease the values of spectral accelerations at elevation of a transport crane in the portal of the NPP reactor compartment with VVER-1500 at seismic impact.

Keywords: Concrete, Dynamics, Response Spectra, Soil-Structure Interaction

1. Statement of research problem

Let's show working-capacity of the technology in question by an example of calculation of response spectra for rather simple structure. It is a transport portal of the NPP reactor compartment with VVER-1500. The model of the reactor compartment with a transport portal is given in Fig. 1. In Fig. 2 the detailed model of a portal with indication of the applied masses, simulating a transport crane with a cargo and a cart is given. The model is developed on the basis of the following structural finite elements:

- beam element of type B31, simulating reinforced-concrete columns and a crossbar, as well as metal beams;
- element of the lumped mass of type MASS, simulating a crane, a cart and cargo;
- element of plate (S4R type), simulating a foundation slab;
- elements of springs (SPRING2 type) and dampers (DASHPOT type), simulating soil (springs were also used to connect cargo and a crane) .

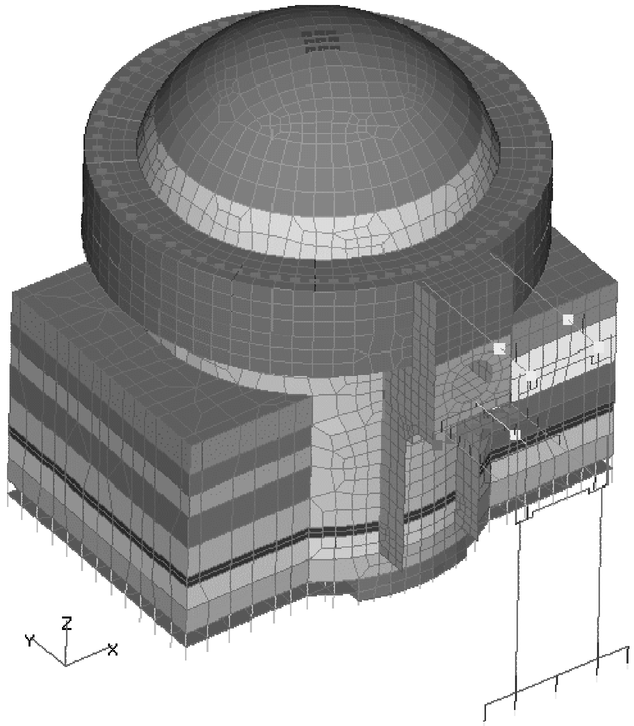


Figure 1. Model of reactor compartment and transport portal.

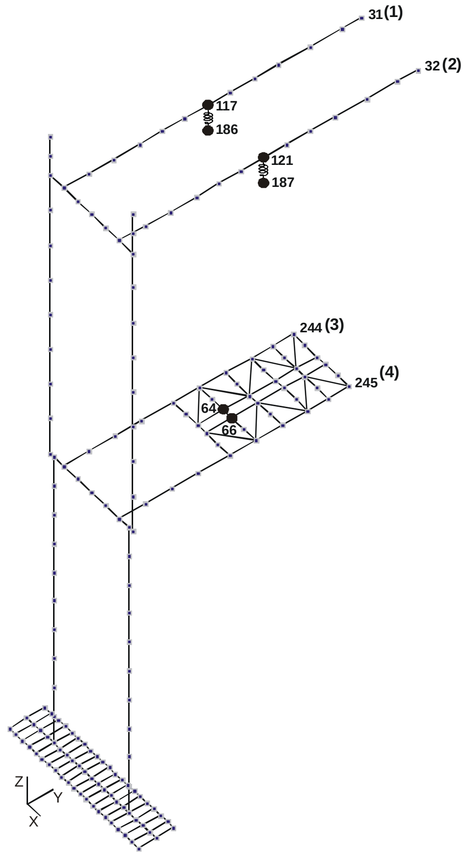
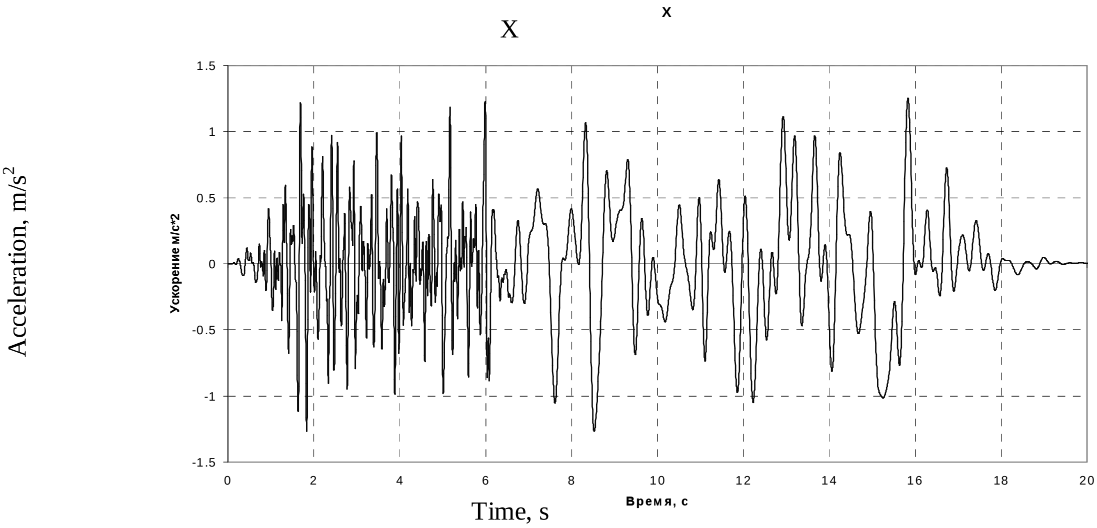
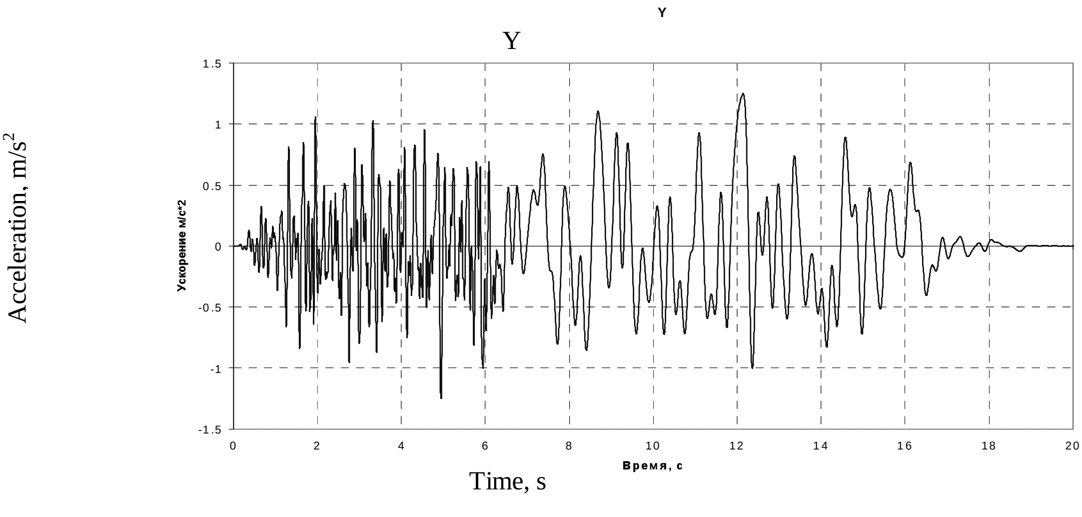


Figure 2. Mathematical model of a portal with indication of the applied masses.

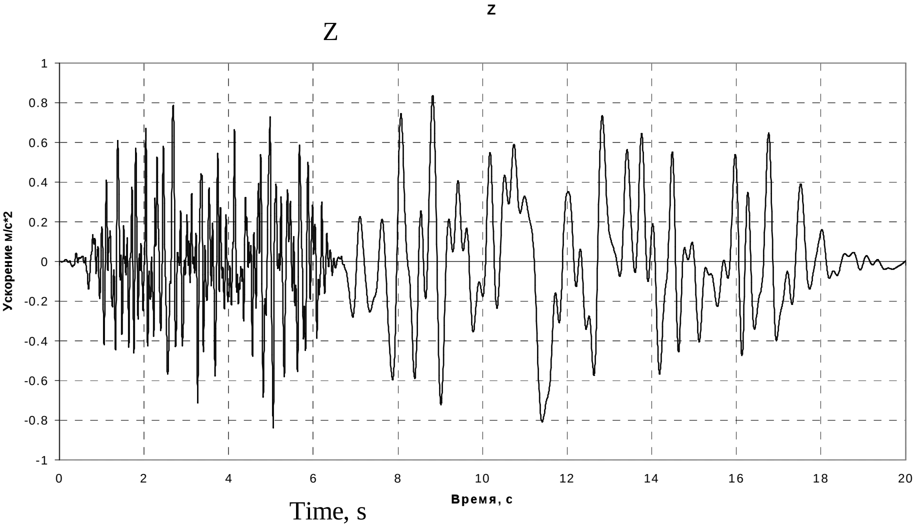
As an external impact, a three-component accelerogram of SSE level (safe shutdown earthquake) with magnitude quake-range of 7 according to MSK-64 scale was applied to a portal foot, see Fig. 3. The accelerograms, obtained from the initial one as a result of complete dynamic calculation of the system, including the reactor building and a portal, were applied to the points of connection of a portal and the reactor building (points 1, 2, 3, 4). Calculations have been made with use of ABAQUS. These accelerograms are given in Fig. 4.





Z

Acceleration, m/s^2

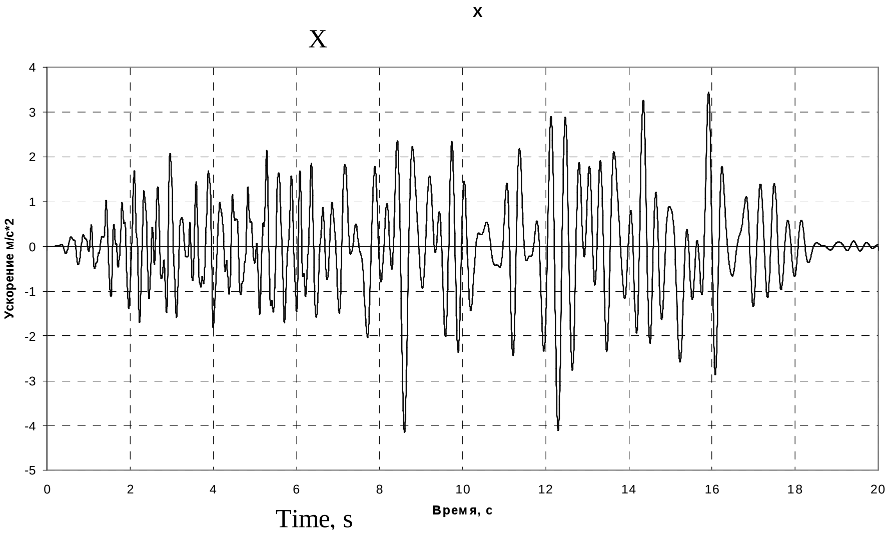


Time, s

Figure 3. Initial accelerogram.

X

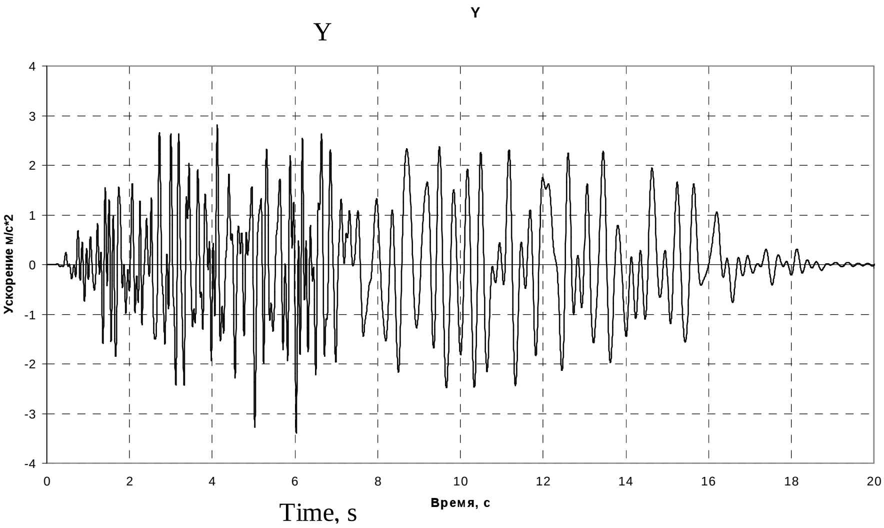
Acceleration, m/s^2



Time, s

Y

Acceleration, m/s^2



Time, s

Z

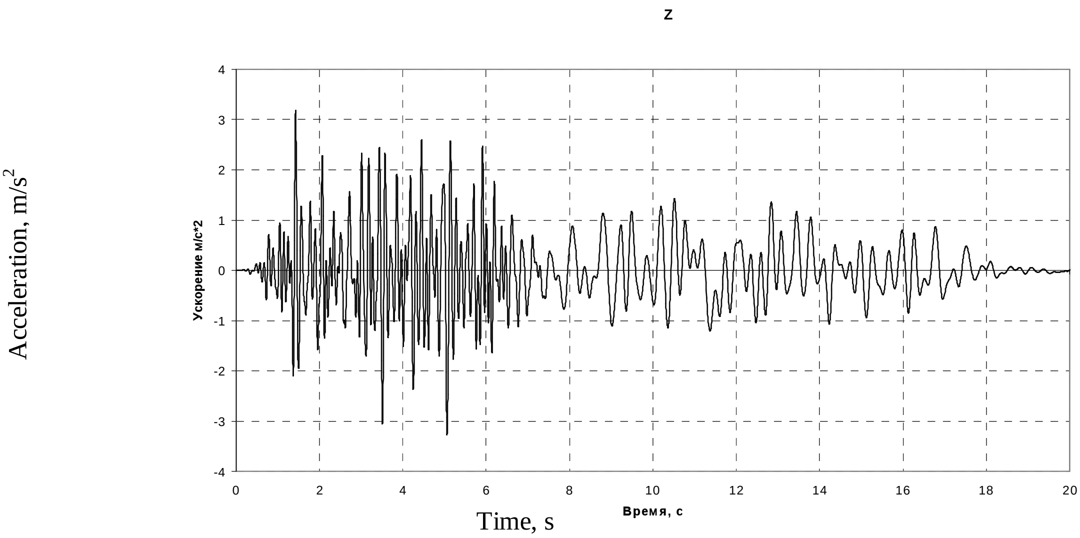


Figure 4. Accelerogram in points of metal beams support.

Dynamic analysis for SSE was made by a method of direct integration at multiplatform loading. First the following system of the equations was solved:

$$\kappa u_i + c u_i' + m \ddot{u}_i = 0, \qquad (1)$$

where u_i, u_i', $\ddot{u}_i$ are vectors of total displacements, speeds and accelerations of the system and k, c, m, – matrixes of rigidity, damping and mass of a system. Initial accelerograms were considered as boundary conditions. After solution of the equation (1), the accelerograms for the locations of a crane and a cart have been obtained. Then at the second stage on the basis of the obtained accelerograms with use of the forced oscillations equation for non-conservative oscillator the response spectra were determined.

The crane mass in calculations was taken as 300 t, a cart mass – 16 t. The cargo mass (200 t) was considered as suspended load which proceeded only in a vertical direction with factor 0,3. Thus, the crane mass with cargo in a horizontal direction was equal to 360 t. Simultaneously exertion of cargo on the cart (216 t) was considered. The detailed description of the initial data and the results is given in [5]. As a result of calculation, enveloping spectra for nine soil sets and then their expansion by 15 % in a frequency range was taken. After on according to [6] the expanded spectra were decreased by 15 % for removal of conservatism due to this expansion, and additionally by 10 % for the account of seismic wave non-coherence.

The analysis of the calculations, made with use of ABAQUS, has shown that the maximum values of spectral accelerations in the locations of the crane are of order 100 g, and in the locations of the cart the acceleration values are of 7 g. It is quite obvious that such loading to the crane is unallowable and therefore strengthening of the top metal beams (location of the crane) has been made. Repeated calculations of response spectra have shown that spectral accelerations in the location of the crane have been decreased and amounted to 20 g. However, it has resulted in increase of load in the locations of the cart, where the maximum spectral accelerations were equal to more than 100 g. In order to decrease loads at the elevation of the crane cart, it was necessary to strengthen the bottom metal beams. As a result, the values of spectral accelerations in the locations of the crane cart have been dropped up to 10 g, but it has resulted in increase of accelerations in the location of the crane installation. Thus, the essential influence of geometrical properties of the top beams on dynamic response of the bottom beams at seismic impact is obvious.

Therefore, as a result of approximately twenty calculations in which geometrical properties of beams have been changed it was possible to lower spectral accelerations in the considered elements of a portal up to 35g. The further decrease in accelerations due to variation of geometry has led to problems.

2. Method of calculation applied to problem of optimization and basic results

So, preliminary investigations showed inefficiency of the non-system design of portal structure. It has suggested to use technology of optimization IOSO NM [2-4] for the case in question.

The optimization method, based on the known Monte-Carlo method in the nonlinear programming, is described in Appendix, and below the following steps necessary to find the optimum parameters are given.

- **a.** The range of parameter changes for the structure considered is plotted.
- **b.** These are thickness of walls and floorings, geometrical characteristics of beams and columns, etc. These varying parameters can be numbered 100 and more.
- **c.** At random 20 points are taken (for some problems number of initial points can be more) within this range. For each of the points, corresponding to different geometry of a structure, the deterministic calculation with use of the ABAQUS is made.
- **d.** Further on interpolation of the calculated characteristics of a parameter from 20 points to all points within the range of parameter change is made (in our case the spectral acceleration values) and as a result the hyper surface is plotted.
- **e.** A minimum functional is determined by the special approximate search method. For the geometrical data, corresponding to this minimum, calculation of characteristics of parameter with use of ABAQUS is made, and the next point is introduced into the range considered. After on calculation is repeated to find a minimum functional, etc. (up to 40 points).
- **f.** Then in case of the multiparameter analysis replacement of parameters by the parameter, having the greatest error, is made, and the process proceeds till any specified accuracy is achieved..

In the report considered the parameters, considerably influencing on the resulting spectra within the limits of these parameters change, have been chosen:

a. Characteristics of cross-section of the top and bottom metal beams of box-shaped type

$1.5m \le a \le 2.5m$;
$2.0m \le b \le 3.0m$;
$1.5m \le a \le 2.5m$,

where (a – width of cross-section, b – height of cross-section, t – profile thickness)

b. Rigidity of vibration isolators in the reference points of the top and bottom metal beams

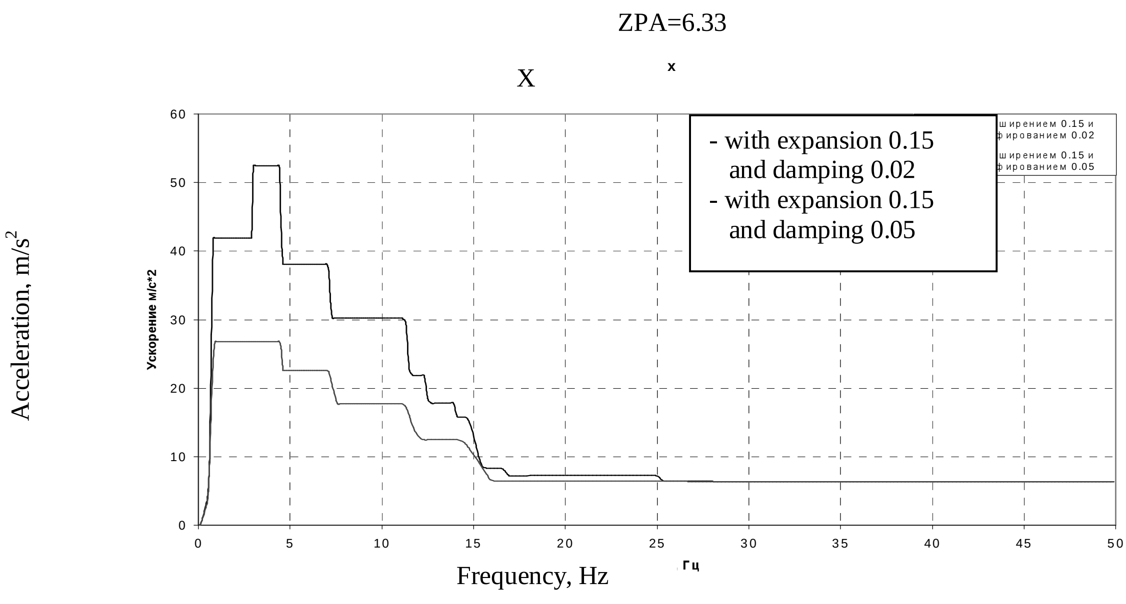
$210t/m \le k \le 1680t/m$.

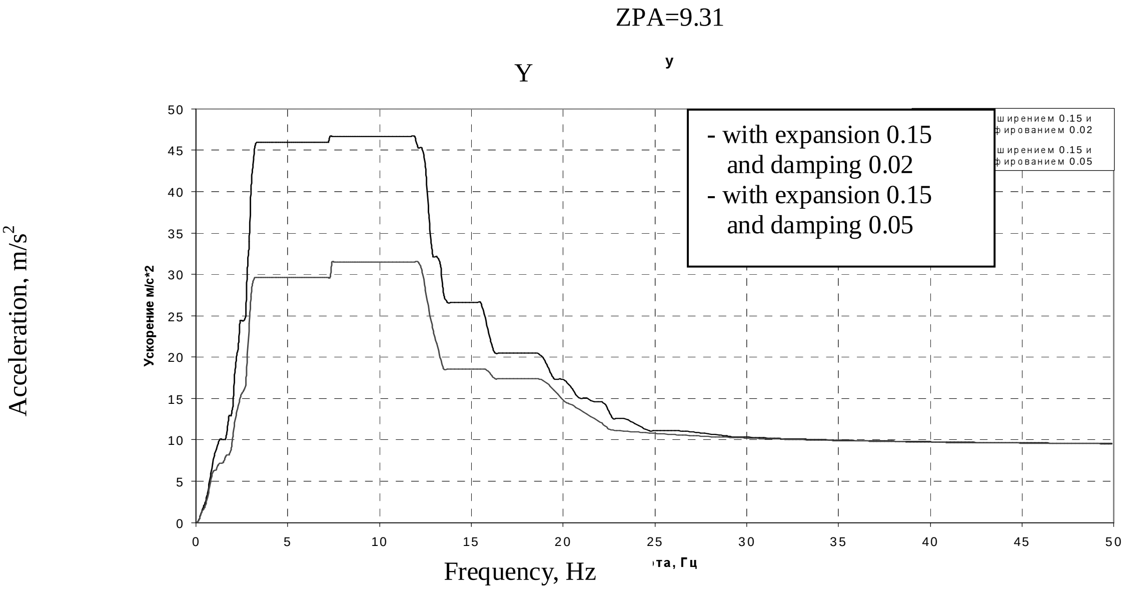
Thus, dimension of optimization problem numbers 8 varying variables. To achieve the specified accuracy 0.01 it was required to make 60 calculations with use of the ABAQUS during optimization. The values of optimum parameters are given in Table below.

Table 1. Values of optimum parameters, realizing a minimum of dynamic response in the portal elements at SSE.

Width of cross-section of top metal beams	**a** = 2,5 m
Height of cross-section of top metal beams	**b** = 2,28 m
Thickness of top metal beam profile	**t** = 0,03 m
Width of cross-section of bottom metal beams	**a** =1,56 m
Height of cross-section of bottom metal beams	**b** = 2,95 m
Thickness of bottom metal beam profile	**t** = 0,03 m
Rigidity of top vibration isolators	**к1** = 1083 t/m
Rigidity of bottom vibration isolators	**к2** = 213 t/m

The response spectra in the locations of the crane and the cart are given in Fig.5 and 6. Response spectra correspond to the characteristics of beams, given in Table 1. Fig. 5 and 6 show that as a result of application of optimization procedure an essential drop in the spectral accelerations can be observed . Peak value of spectral acceleration equals to 12 g and corresponds to vertical vibrations of beams in the locations of the cart.





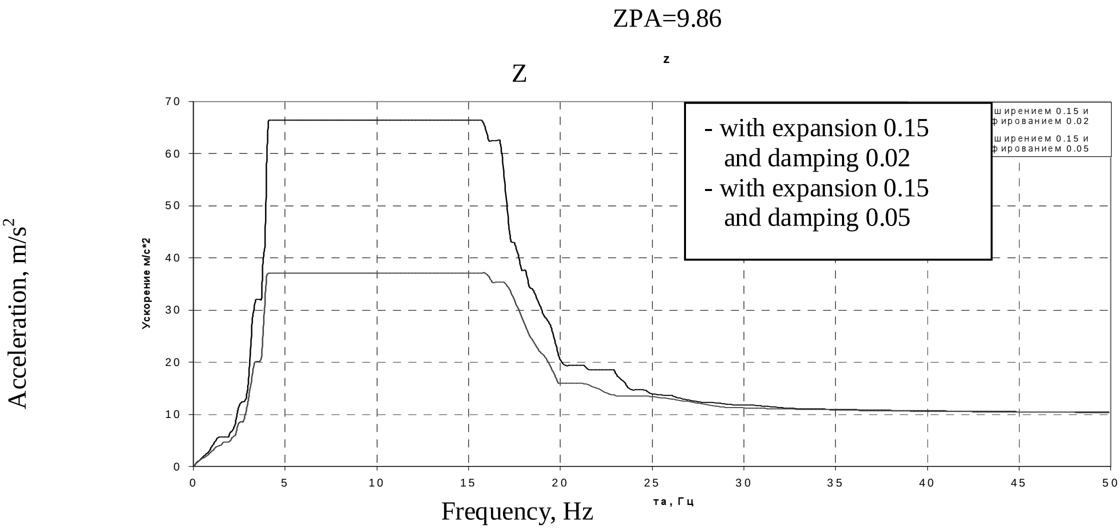
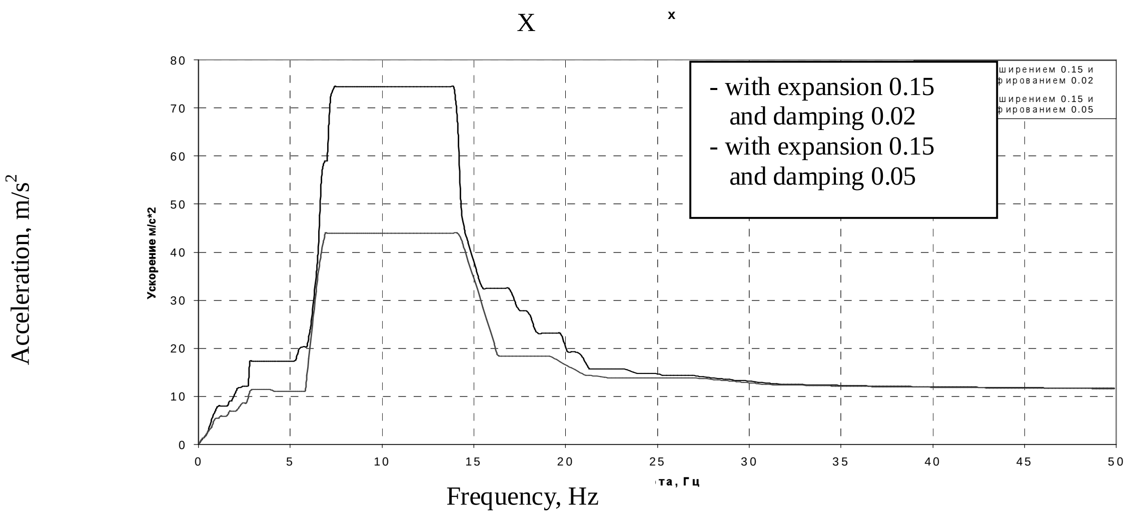
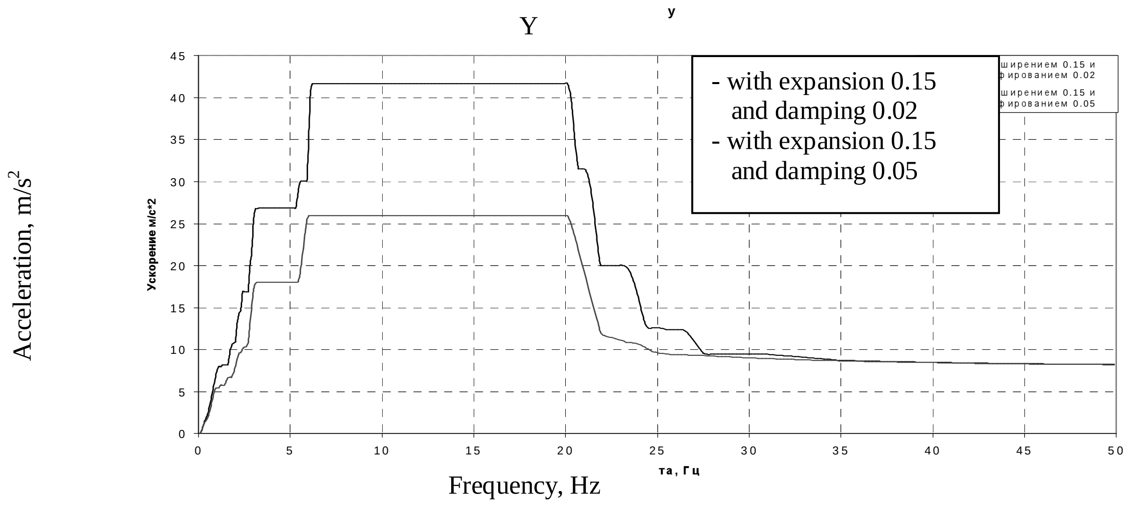


Figure 5. Enveloping response spectra from SSE on the top metal beams (crane).

ZPA=10.89



ZPA=8.12



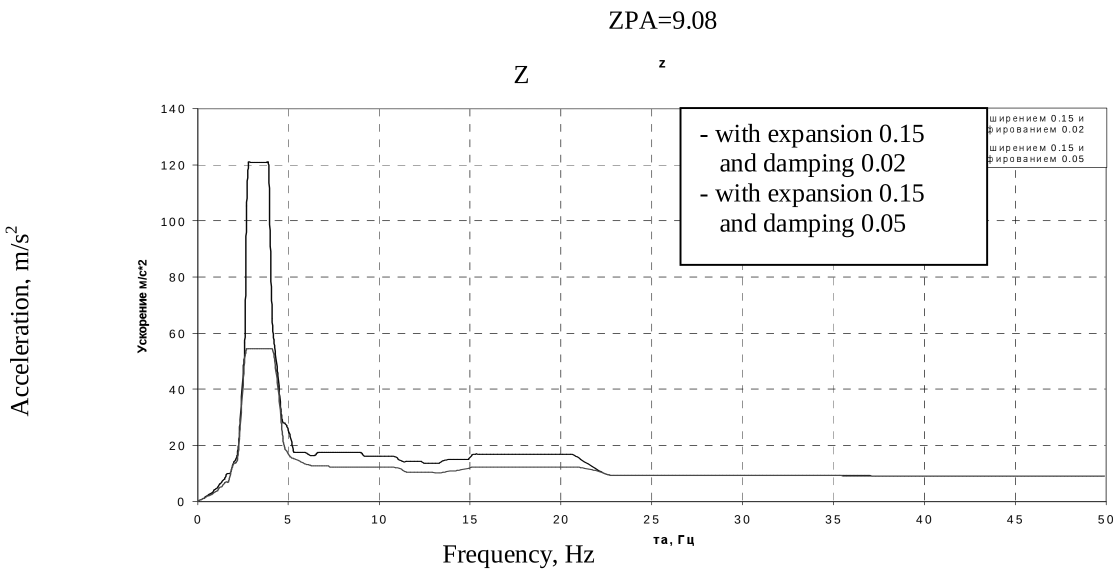


Figure 6. Enveloping response spectra from SSE on the bottom metal beams (cart).

Investigation of a transport portal optimization can be continued, having involved all possible parameters and criteria which to some extent can influence on the result. The account of these factors can lead to the further decrease in spectral accelerations.

3. Conclusions

For designing of NPP civil structures ABAQUS and technology of multiparameter optimization IOSO have been applied.

Use of such system approach for choice of optimum parameters with the purpose to make calculation of response spectra has allowed to decrease twice as much the spectral acceleration values at elevation of a transport crane in the portal of the reactor compartment of NPP with VVER-1500 at seismic impact.

4. References

1. Soft-and-hardware complex ABAQUS 6.6.1 (USA).
2. Egorov I.N., "Indirect Optimization Method on the Basis of Self-Organization", Curtin University of Technology, Optimization Techniques and Applications (ICOTA'98), Vol.2, pp. 683-691, Perth, Australia, 1998.
3. Egorov I.N., Kretinin G.V., Leshchenko I.A., "Two Approaches to Multidisciplinary Optimization Problems", presented at European Congress on Computational Methods in Applied Sciences and Engineering – ECCOMAS-2000, Barselona, Spain, 2000.
4. Egorov, I.N., Kretinin, G.V., Leshchenko, I.A., "Robust Structure Optimization Strategy of IOSO Technology". WCCM V, July 7…12, 2002, Vienna, Austria.
5. Report of FSUE Atomenergoproekt – Response spectra for seismic impacts on portal crane. inv. No.1525 dated 31.03.06.
6. ASCE 4-98. ASCE STANDARD. Seismic ANALYSIS OF safety Related Nuclear Structures and Commentary. Approval 1998