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CALCULATED DETERMINATION OF THE SEISMIC RESISTANCE OF NUCLEAR POWER PLANT EQUIPMENT

Serhii A. Palkov
sergpalkov@gmail.com
ORCID: 0000-0002-2215-0689

Ihor A. Palkov
igorpalkov1987@gmail.com
ORCID: 0000-0002-4639-6595

Joint-Stock Company
Turboatom
199, Moskovskyi Ave.,
Kharkiv, 61037, Ukraine

An algorithm to confirm the seismic resistance of equipment by a calculation method is proposed, and the limits of its application are determined. A mathematical model of the equipment is developed, and an example of the determination of natural frequencies and stresses for a three-dimensional structure is given. Two main types of calculation were used – static and dynamic. In the static calculation, the stress-strain state of a structure was determined. The values of the obtained stresses were compared with the allowable ones for the materials used, on the basis of which conclusions were made about the strength of the structure under seismic effects. The dynamic calculation resulted in the determination of the rigidity of the structure. The comparison of the stress values obtained for this equipment allowed us to make a conclusion regarding its resistance to seismic effects. The seismic resistance of the equipment was estimated on the example of the K-1000-60/1500 steam turbine condenser, and calculated at a seismic intensity of 6 points on the MSK-64 seismic intensity scale. In the course of solving this problem, results of the stress distribution in the housing and other structural elements of the condenser due to the action of combined normal operation and design-basis seismic loads were obtained. The seismic resistance of the equipment was calculated using the finite element method. This allowed us to present a solid body in the form of a set of individual finite elements that interact with each other in a finite number of nodal points. To these points are applied some interaction forces that characterize the influence of the distributed internal stresses applied along the real boundaries of adjacent elements. To perform such a calculation in CAD modeling software, a three-dimensional model was created. The obtained geometric model was imported into the software package, which significantly reduced complexity. The use of the calculation method allows us to significantly reduce the amount of testing when confirming the seismic resistance of equipment. Results of the assessment of the spatial complex stress state of the steam turbine condenser design due to the action of combined normal operation and design-basis seismic loads are obtained.

Keywords*: turbine, seismic resistance, stress, earthquake, accelerogram, finite element, natural frequency.*

Introduction

Work to confirm the seismic resistance of various-purpose equipment is due to the active construction of facilities in seismic zones, changes in regulations regarding seismic resistance, and the creation of new types of equipment (including large), which were not previously required to be seismic-resistant.

At present, there is a general tendency to reduce the number of tests, full-scale mock-ups, and use more favorable test modes, which is caused by their high complexity and cost. However, even a low-intensity seismic effect creates complex problems that are required to be promptly resolved. This means that during earthquakes, at an explosive energy-industry facility where a variety of electrical equipment with different dynamic characteristics is used, disruptions in electricity supply and facility control may occur. At such hazardous objects as nuclear power plants, it is recommended to take into account all the seismic effects, beginning from four-point ones, and all the electrical equipment must be supplied with documentation confirming its seismic resistance.

Calculation for seismic resistance is an obligatory step in the verification of turbine equipment, and is used to determine the possibility of using in seismic zones of power plant equipment designed in accordance with the requirements of regulations. At present, requirements for the seismic resistance of power equipment have become obligatory in the design of not only nuclear, but also thermal power plants located in seismic zones. The great attention paid to the issue of ensuring the seismic resistance of power plant equipment is determined not only by the risk of radioactive contamination of the environment, deaths of people, large material losses during earthquakes, but also the ability to significantly increase the reliability of equipment under normal operating conditions [1]. This is due to the fact that seismic resistance calculation is essentially an additional analysis of the entire structure under a dynamic effect, which has a wide range of frequencies from fractions to

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several tens of hertz, and includes almost all the operating and natural frequencies of equipment. As a result, already at the design stage, weak structural elements are detected, which cannot be detected by traditional methods of analysis. According to the general seismic-resistant design approach, the seismic resistance of a turbine is considered to be ensured if the design-basis seismic (DBS) effect does not disrupt the turbine performance, and provides electricity generation with unguaranteed efficiency during and after the earthquake.

Seismic requirements are regulated differently in domestic and foreign standards. In the post-Soviet space, the main requirement is GOST 17516.1-90 [2] for commissioned nuclear power plants (NPP) and design standards NP-031-01 [3] for newly constructed ones. Of the foreign standards, the IEC 60980 standard is fundamental in terms of seismic resistance (seismic qualification) [4]. The same standards contain recommendations for the application of a calculation method to confirm seismic resistance.

The calculation method allows us to confirm the seismic resistance of large-sized equipment, the equipment that is already in operation (for example, during modernization), summarize the test results for the seismic resistance of one piece of equipment for a series of similar pieces of equipment. It is also important to be able to predict the test results and make their calculated correction when it is impossible to create normal conditions for them.

The calculation method includes several main stages:

– analysis of requirements;

– creation of a mathematical model of equipment;

– calculation of a structure for the loads specified.

The algorithm for the calculation-based verification of seismic resistance should use two main types of calculation – static and dynamic. In the static calculation, stresses and displacements in a structure are compared with the allowable values for the materials used, on the basis of which a conclusion is made regarding the strength of the structure under seismic effects [5]. The dynamic calculation results in the determination of the rigidity of the structure. The comparison of the obtained stress values with the allowable ones for this equipment allows us to a conclusion regarding its resistance to seismic effects.

There are several ways to specify seismic effects [3, 4] the main ones of which are to use a seismic accelerogram, response spectra, or the intensity of a seismic effect in points on the MSK-64 scale.

Issues of the estimated assessment of the seismic resistance of power plant equipment have been studied in the works of many prominent scientists and research institutes [6–13].

In [8], results of studying the seismic fragility of equipment of nuclear power plant components are highlighted. An example of a simplified model of the reactor vessel supported by the foundation insulation system is given. In [9], a methodology to analyze the seismic resistance of NPPs in Slovakia is considered, which is based on new results of geological and seismotectonic monitoring. Seismic loads based on probabilistic seismic hazard analysis are described. In [10], results of scientific researches, conducted by specialists of "CKTI-Vibroseism" together with the GERB company, of the process of optimizing the static and dynamic characteristics of the offered spring-damping three-component system of seismic isolation in the conditions of operation of a power unit with the VVER-1200 reactor are given. In [12], the dynamic response of a structure with three-dimensional insulation systems is studied, where the authors, based on the obtained results, give recommendations regarding the introduction of additional system constraints. In [13], the authors present the results of studying the seismic resistance of building structures, using the response spectra obtained during the earthquake in Kumamoto, Japan. The influence of various structural insulating elements on the stress state of buildings is studied.

Based on this general principle, in this work, in accordance with [14], the seismic resistance of elements of the K-1000-60/1500 steam turbine condenser was assessed according to the technique based on the finite element method (FEM) [15].

This seismic resistance calculation was performed at a seismic intensity of 6 points on the MSK-64 scale. In the course of solving this problem, results of stress distribution in the housing and other structural elements of the steam turbine condenser from the action of combined normal operating (NO) and design-basis seismic (DBS) loads were obtained.

Features of the Condenser Design

The K-1000-60/1500 turbine condenser consists of three identically designed condensers, connected by transition pipes with the exhaust pipes of the turbine [16, 17]. Exhaust steam from the three low-pressure cylinders (LPC-1, 2, 3) enters the two side condensers located on both sides of LPCs. The support system of the side condensers provides the relative temperature displacements of "LPC-condenser" system elements. On each LPC side, there are four exhaust pipes of rectangular cross-section. On each side an LPC is connected with the condenser housing by means of transition branch pipes through the use of four inserts with lens compensators. At the entrance to the condenser housing, each pipe has a rectangular cross-section whose height corresponds to the height of the condenser housing, and the width, to half of its length. When a diffuser-design pipe is used, the speed of steam entry into the condenser housing is reduced, and a uniform steam distribution along the entry section of the pipe bundle is provided. The connection of the pipes with both the condenser housings and the intermediate compensating elements of LPCs is performed by welding. At such a connection of an LPC with the condenser housing, there occur lateral forces that act on the condenser housing towards the LPC, and are determined by pressure difference and the area of its exhaust branch pipes.

The forces acting on each condenser are transmitted to the turbine foundation by flexible side supports, which are installed on both sides of the pipe bundle between the condenser and the turbine foundation (only four groups of two supports).

The supports are made of pipes. Each pipe is rigidly attached on one side to the condenser housing near the pipe end plates and specially reinforced water chambers, and on the other, to the metal structures embedded in the foundation.

The load from the weight of the condenser with water is carried by a system of flexible rods located along the condenser. On the outside of the condenser, the support has one row of rods, on the inside (at the adapter), two rows, each having 24 rods. Such a support is rigidly embedded in the structural elements of the bottom plate of the foundation, and welded to the condenser.

According to the conditions of arrangement of condenser circulation pipelines, the supply and removal of the cooling water is executed in the lower parts of water chambers.

Problem Statement and Description of Calculation Methods

The calculation of equipment for seismic resistance in this work was performed using FEM. This method allows us to present a solid body as a set of individual finite elements (FE). They interact with each other in a finite number of nodal points, to which are applied some interaction forces that characterize the action of distributed internal stresses applied along the real boundaries of adjacent elements. The problem reduces to calculating an elastic system with a finite number of degrees of freedom. Replacing the original structure with a set of discrete elements implies the energy equality of the structure and its discrete model. The stresses in these elements are determined by a combination of stresses from specified and dynamic loads. The resulting stresses are compared with the allowable ones.

An FE model of equipment is created on the basis of design documentation, which can be submitted in the form of paper or electronic drawings, as well as in the form of a three-dimensional model. The first two options are most common. When they are used, the geometry of the FE model requires to be created anew.

To perform this calculation on a scale of 1:1, CAD modeling software was used to create a three-dimensional model of the K-1000-60/1500 steam turbine condenser (Fig. 1). The obtained geometric model was imported into the software package, which significantly reduced complexity. In the package, the geometric model was divided into finite elements, the properties of materials were specified, and boundary conditions were applied.

The structural response to seismic loads is determined from the generalized seismic load [18], using the structural calculation method.

The calculation of a structure according to the above method can be divided into three stages.

1. Calculation of natural frequencies and forms of structural oscillations.

The calculation of free oscillations is performed without account taken of dynamic loads, but is the first and obligatory step in solving more complex dynamic problems [18].

The differential equation of free oscillations has the following form:

$$[\mathrm{M}]\{x\}+[\mathrm{K}]\{x\}=0 .$$

The analysis of free oscillations assumes the elastic behavior of the structure, so the expected response is harmonious

$$\{x\}=\{\phi_j\}\cos(\omega_j t) ,$$

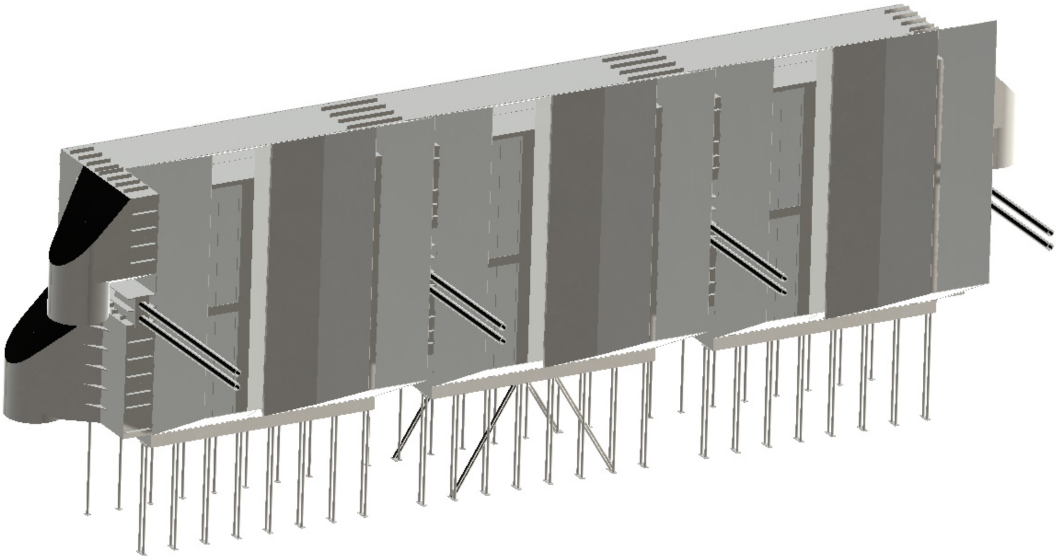

Fig. 1. Three-dimensional model of the K-1000-60/1500 steam turbine condenser

where ϕ_j determines the form of oscillations of the *j*-th mode (eigenvector) and ω_j is the natural frequency for this mode.

Substitution in the previous equation yields

$$-\omega_j^2[\mathrm{M}]\{\phi_j\}\cos(\omega_i t)+[\mathrm{K}]\{\phi_i\}(\omega_i t)=0,$$

$$(-\omega_j^2[\mathrm{M}]+[\mathrm{K}])\cdot\{\phi_j\}\cos(\omega_j t)=0.$$

The natural frequencies ω_i can be found from the equation

$$([\mathrm{K}]-\omega_j^2[\mathrm{M}])\cdot\{\phi_j\}=0.$$

2. Calculation of modal (corresponding to each of its eigenforms) inertial seismic loads on the structure for a given direction of effect.

To determine seismic loads in a spatial dynamic system with three-component seismic interaction, which is given by the response spectra for three mutually perpendicular directions, the following formula is used [19, 20]

$$\{S\}_j=[M]\{X\}_j\frac{\{X\}_j'[M](\{\cos a\}_x\alpha_{jx}+\{\cos a\}_y\alpha_{jy}+\{\cos a\}_z\alpha_{jz})}{\{X\}_j'[M]\{X\}_j},$$

where $\{\cos a\}_x$, $\{\cos a\}_y$, $\{\cos a\}_z$ are the vectors of the guide cosines of the angles between the generalized coordinates of the system and the direction of seismic interaction along the coordinate axes *x*, *y*, *z*, respectively; α_{jx}, α_{jy}, α_{jz} is the acceleration with the frequency ω_j determined by the response spectra in the directions *x*, *y*, *z*, respectively.

3. Determination in the cross-sections of the condenser of the values of stresses and displacements resulting from the action of seismic and operational loads.

To determine the calculated values of stresses in the cross-sections of a structure, the values of resulting internal forces are used. These values are calculated by sequentially taking into account, in the calculation model, a system of seismic loads, and then summed up by the root-mean square dependence [19]

$$N_k^p=\sqrt{\sum_{j=1}^{S}N_{kj}^2},$$

where N^p_k is the resulting force of a certain type on the k-th cross-section under consideration, N_{kj} is the magnitude of the force of a certain type on the k-th cross-section, obtained for the j-th mode of oscillations.

The magnitudes of structural displacements during seismic interaction are determined by the formula

$$x_i = \sqrt{\sum_{j=1}^{S} x_{ij}^2} \,,$$

where x_i is the calculated value of the displacement of a structure point in the direction of the i-th generalized coordinate (i=1…N); x_{ij} is the i-th element of the vector $\{x\}_j$, which is the displacement of a structure point in the direction of the i-th generalized coordinate with oscillations along the j-th eigenform.

Given that the considered condenser design is in a complex stress state, the assessment of its strength is based on the analysis of principal stresses according to the Mises–Genk limit state theory, also known as the distortion energy theory [21].

The three values of the principal stresses σ_0 represent the roots of the cubic equation determined by the components of the stress vector

$$\begin{vmatrix} \sigma_x - \sigma_0 & \frac{1}{2}\sigma_{xy} & \frac{1}{2}\sigma_{xz} \\ \frac{1}{2}\sigma_{xy} & \sigma_y - \sigma_0 & \frac{1}{2}\sigma_{yz} \\ \frac{1}{2}\sigma_{xz} & \frac{1}{2}\sigma_{yz} & \sigma_z - \sigma_0 \end{vmatrix} = 0 .$$

The principle stresses are denoted by σ_1, σ_2 and σ_3, and are ordered in such a way that σ_1 is the largest positive stress and σ_3 is the largest negative one.

In calculating the principal stresses σ_1, σ_2 and σ_3, the equivalent von Mises stresses are given as

$$\sigma_{\text{equiv}} = \sqrt{\left\{ \frac{\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2 \right]}{2} \right\}} .$$

The equivalent stresses are related to equivalent strains by the following relation:

$$\sigma_{\text{equiv}} = 2 \in_{\text{equiv}} G ,$$

where $G = E/(2(1+\nu))$ is the shear modulus; E is Young's modulus; ν is Poisson's ratio.

The seismic resistance of a structure, when the normal operating (NO) loads and design-basis seismic (DBS) loads are combined, is verified by comparing the obtained total stresses with the corresponding allowable values according to [19].

In this study, the following NO and DBS loads were taken into account [17, 19].

The NO loads are:

– the weight of the condenser with water, in operational condition, m=1659.5 t;

– the atmospheric pressure acting on the condenser housing from the outside;

– the pressure of the cooling water in the heat exchange pipes, side and intermediate water chambers P_{wtr}=0.2 MPa.

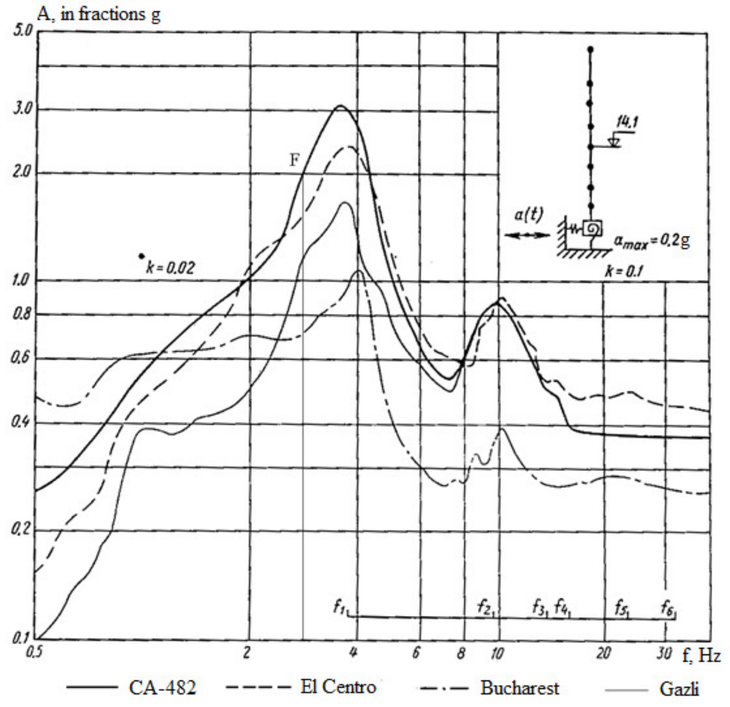

Fig. 2. Surface response spectra at a height of 14.1 m of the reactor building [19]

Considered as the DBS loads are the inertial seismic loads given by the response spectra in the directions x, y, z with the corresponding accelerations with the frequency ω_j. To be able to simulate the dynamic effect, the bottom plate of the foundation is taken to be absolutely rigid. The calculated stiffness of the compensator between the LPC and condenser was: $5 \cdot 10^7$ N/m along the turbine axis and $1 \cdot 10^7$ N/m in the direction of steam supply from the LPC to the condenser through the adaptors.

To calculate the K-1000-60/1500 steam turbine condenser design, only the synthetic accelerogram CA-482 was used, which was caused by the lack of seismic data at possible unit installation sites. The accelerogram, taken from [19] and shown in figure 2, was reduced to an intensity of 6 points on the MSC-64 scale (maximum acceleration on the ground is 0.05g). The principle of constructing the accelerogram makes it possible to provide an 80% probability of not exceeding the structural response in comparison with seismic structural stability calculations for real accelerograms. Thus, in the vast majority of cases, in designing advanced equipment is provided the accuracy of calculations that is not tied to a specific construction site, as evidenced by the experience of its use [19]. The response spectra were obtained for the relative damping κ=2%. The accuracy of calculations is provided by placing the condenser housing at a height of about 4 m instead of 14 m, for which the accelerogram was built.

Preparation of the FE model

When creating the FE model of static and dynamic problems, a 10-node three-dimensional tetrahedral FE was used (Fig. 3) [15, 22]. This element allows us to specify boundary conditions depending on the type of kinematic connection, namely displacements, velocities, accelerations, etc.

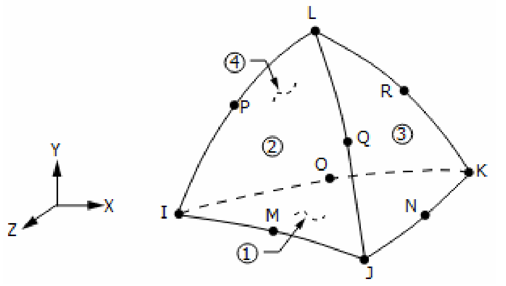

Fig. 3. Geometry of a 10-node FE [15]

When choosing the FE model, an analysis was performed to determine the optimal FE size. As a result of the analysis it was determined that the optimal FE size is 150 mm. With a further decrease in the FE size, the accuracy of calculation changes insignificantly, with the number of elements growing rapidly. The general view of the calculated FE model of the condenser is shown in figure 4. When the original model was broken, about 2.1 million finite elements and 4 million nodes were obtained.

Fig. 4 shows separate fragments of the calculated FE model of the condenser: A – side chamber; B – intermediate chamber; C – oblique supports under the middle condenser; as well as side and vertical supports.

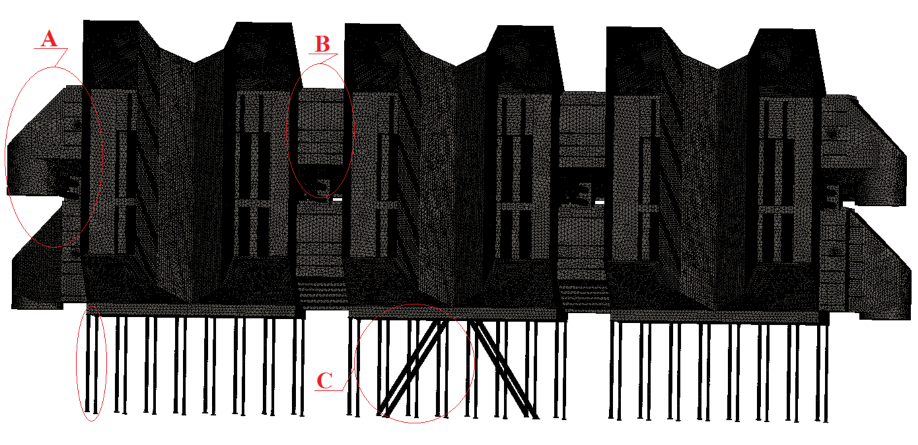

Fig. 4. FE model of the condenser

Analysis of the Results Obtained

For the condenser, the eigenforms of oscillations were obtained, whose frequencies are given below.

Form No.	1	2	3	4	5
Frequency, Hz	2.6379	3.5551	3.5583	3.5735	3.5855

These eigenforms of oscillations are shown in figure 5.

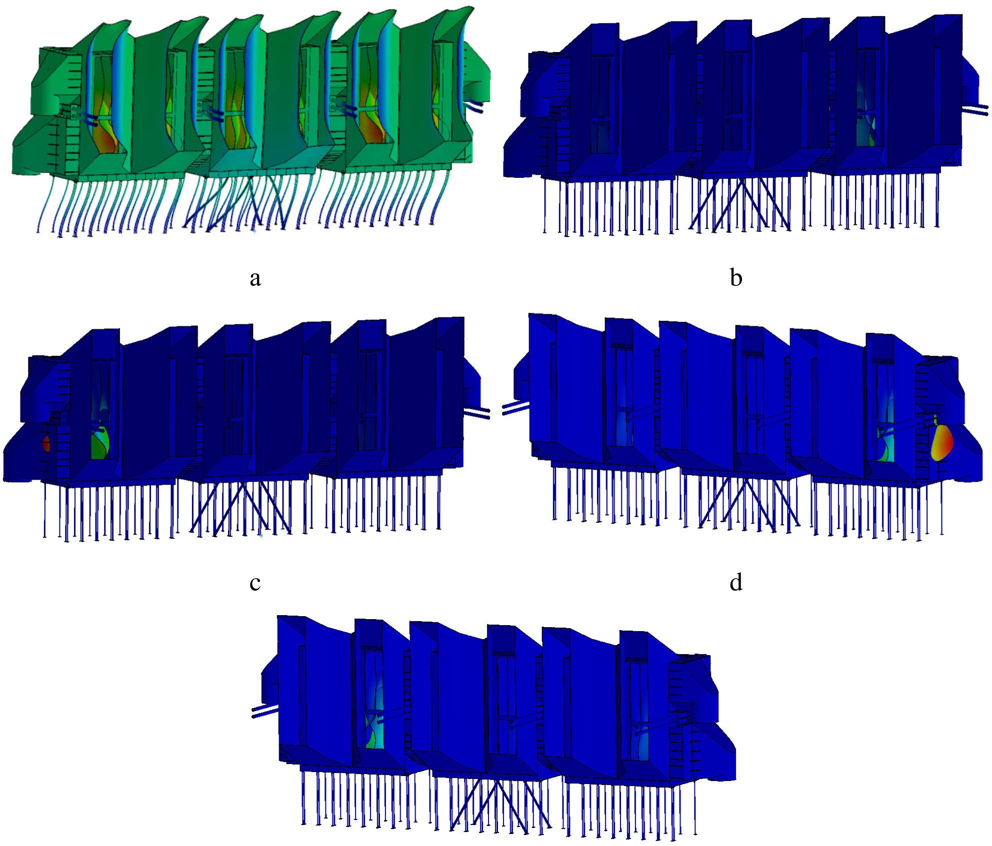

Fig. 5. Forms of condenser oscillations, Hz:
a – first, 2.6379; b – second, 3.5551; c – third, 3.5583; d – fourth, 3.5735; e – fifth, 3.5855

The forms of condenser oscillations shown in figure 5 are characterized by considerable complexity. The obtained results can be described as follows.

The first form is the largest amplitude of oscillations of the condenser structure in the horizontal direction (Fig. 5, a).

The second form is the oscillations of the rear wall of the condenser housing in the area of the 2nd (on the right) adapter (Fig. 5, b);

The third form is the oscillations of the rear wall of the condenser housing in the area of the 1st (on the left) adapter (Fig. 5, c).

The fourth form is the oscillations of the front wall of the lower right water chamber (Fig. 5, d).

The fifth form is the oscillations of the rear wall of the condenser housing in the area of the 2nd (on the left) adapter (Fig. 5, e).

The analysis of the experimental studies of the seismic resistance of such structures [19, 20] showed that in the field of seismic resonance is only the first natural frequency. Higher natural frequencies are at a considerable distance from the region of seismic resonance. Usually the second natural frequency is above the upper limit of the spectral curve. In this paper, the calculation of the first five natural frequencies is performed.

According to [3, 14] and by analogy with the formula

$$\mathrm{A}_{calc} = \sqrt{\mathrm{A}_x^2(f_1) + \mathrm{A}_y^2(f_1) + \mathrm{A}_z^2(f_1)}\ ,$$

at the first natural frequency (Fig. 5), using the synthetic accelerogram CA-482 (at this frequency at a point we actually get the doubling of the inertial load relative to the ground) and using the value of the maximum level of DBS accelerations [19]), we find the inertial seismic loads (accelerations), which equal to a=0.98 m/s^2 for the horizontal plane and are 67% of the horizontal component for the vertical one.

The maximum level of DBS accelerations [19] is given below

Seismic resistance of the site	5	6	7	8	9	10
Maximum level of accelerations (in fractions of g)	0.025	0.05	0.1	0.2	0.4	0.8

Taking into account that the calculation model is a holonomic, conservative system with a limited number of degrees of freedom, we use the method of direct integration of equations of motion, namely the Lagrange equations of the second kind [23]

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_i}\right)-\frac{\partial T}{\partial q_i}=N_i \quad (i=1,\ldots,n)\,,$$

where t, q_i, $\dot{q}_i$ (i=1, …, n) are the Lagrange variables through which the Lagrange function is expressed; T is the kinetic energy; N_i is the generalized force.

The condenser housing is made of grade 20 carbon steel. Nominal admissible stresses are calculated according to the norms [2] by the formula:

$$[\sigma]=\min\left\{R_{str}^{T}/2.6;\ R_{calc0.2}^{T}/1.5\right\}.$$

Permissible stresses are calculated according to the norms [6], and are given below:

– material is grade 20 carbon steel;

– $R_{calc\,0.2}^{50}$ =216 MPa is the minimum value of the yield strength at the design temperature T=50 ºC;

– R_{str}^{50} =363 MPa is the minimum value of the tensile strength at the design temperature T=50 ºC;

– $[\sigma]$ =140 MPa is the nominal value of allowable stresses;

Combined NO and DBS loads $(\sigma_s)_2=1.9\cdot[\sigma]$, MPa=265 MPa.

As a result of solving the problem of determining the stress-strain state when the NO and DBS loads are combined, the distribution of equivalent stresses in the structure of the condenser (Fig. 6) and in elements of its housing (Fig. 7) is obtained.

The maximum equivalent stresses in the condenser housing elements, as shown in figure 6, when the NO and DBS loads were combined, equaled 236 MPa, which does not exceed the allowable value of 265 MPa.

In addition to the maximum equivalent stresses, with the NO and DBS loads combined in the condenser supports, the stress-strain state during seismic interaction was also assessed from the displacements of the supports (Fig. 8).

As can be seen from the figure, for the considered load level, the displacement of the condenser supports in the direction of the turbine axis does not exceed 6 mm.

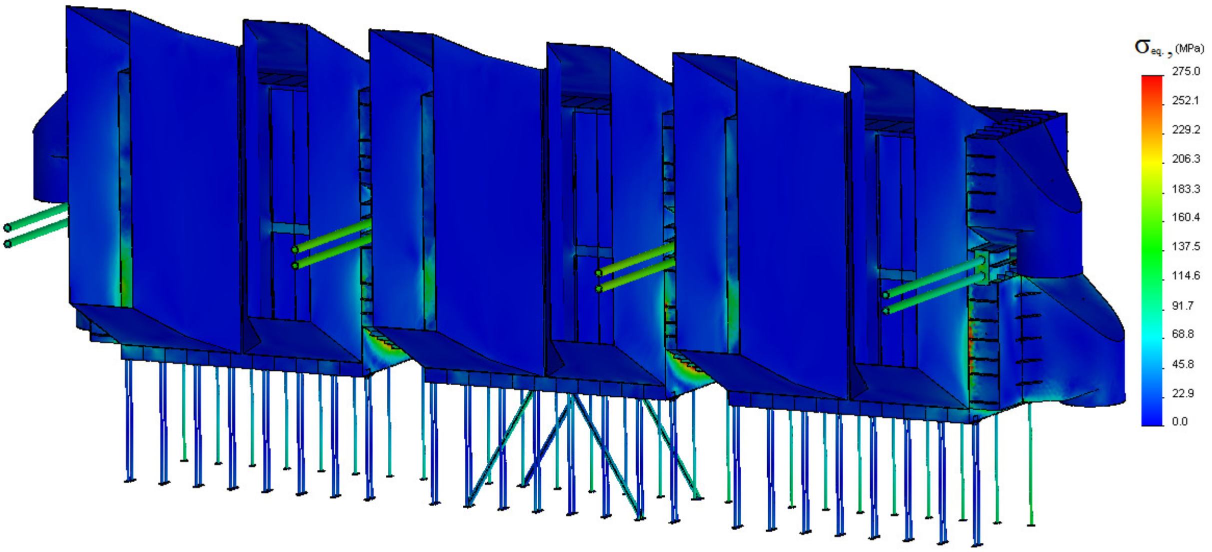

Fig. 6. Distribution of equivalent stresses with the NO and DBS loads combined

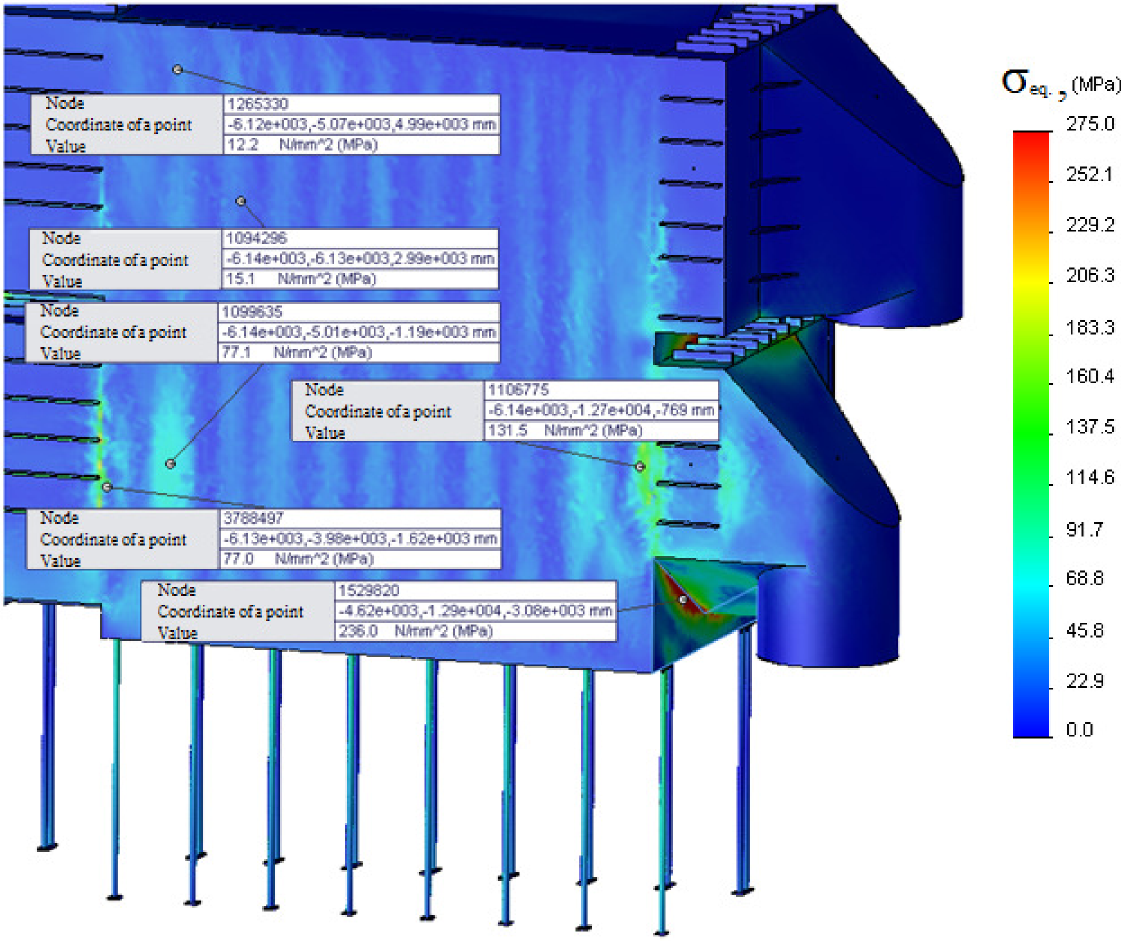

Fig. 7. Distribution of equivalent stresses in the condenser housing with the NO and DBS loads combined

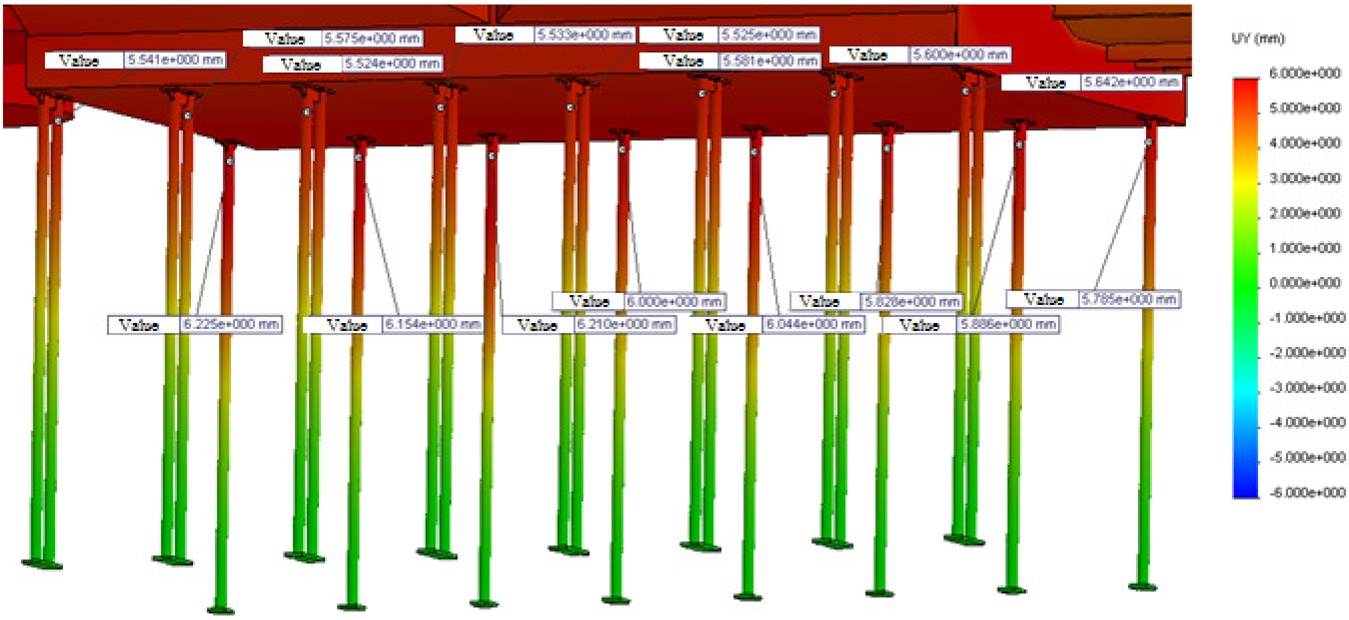

Fig. 8. The distribution pattern for displacements in the direction of the turbine axis in the condenser supports with the NO and DBS loads combined

Conclusions

Guaranteeing seismic resistance, which is important for the safety of power plant equipment, is a very important task.

The currently used calculation methods for substantiating seismic resistance, due to a number of simplifications previously dictated by the limited capabilities of the software and computer base, do not always meet the ever-increasing requirements of a comprehensive assessment of the reliability characteristics of the "foundation-turbine unit" system equipment.

The development of calculation programs and hardware allowed us to significantly improve the quality of model preparation and use complex dynamic calculations. This makes it possible to considerably reduce the amount of testing when confirming the seismic resistance of equipment.

The relevance of this work consists in developing methods to increase the efficiency of the calculated substantiation of the seismic safety of power plant equipment by realizing the possibility of reducing the volume and cost of work caused by in-situ tests. The aim of the work is to study the possibility of replacing these tests with a numerical experiment while maintaining the required level of confidence and reliability of the seismic assessment of equipment.

An algorithm for confirming the seismic resistance of equipment by a calculation method is proposed.

A mathematical model of equipment is developed, and an example of determining the natural frequencies, stresses and displacements in a structure is given.

In the course of work, the natural frequencies were determined, and the structural strength was calculated with the assessment of seismic resistance.

In the first stage of solving the problem, the values of the first five natural frequencies of the condenser design and their oscillation forms were obtained. The lowest natural frequency was 2.6379 Hz.

Taking into account the values of natural frequencies at the second stage of solving the problem, the loads for strength calculation were determined, which were selected based on the lower resonant frequency according to the synthetic accelerogram CA-482 with account taken of the seismic intensity of equipment according to RTM 108.020.37-81.

The calculation was performed under the simultaneous action of loads in the vertical and horizontal directions. The results of this calculation enable us to conclude that the margin of safety of this condenser structure is sufficient for a 6-point seismic effect.

This technique allows us not only to determine the features of the complex stress-strain state of the equipment that directly interacts with the foundation and carries the load during an earthquake, but also allows determining the boundary conditions for further analysis of the reliability of related equipment.

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Розрахункове визначення сейсмостійкості обладнання атомних електростанцій

С. А. Пальков, І. А. Пальков

Акціонерне товариство «Турбоатом», 61037, Україна, м. Харків, пр. Московський, 199

Запропоновано алгоритм підтвердження сейсмостійкості обладнання розрахунковим методом і визначено межі його застосування. Розроблено математичну модель обладнання і наведено приклад визначення власних частот та напружень в конструкції в тривимірній постановці. Використано два основних типи розрахунку – статич-

ний і динамічний. У статичному розрахунку визначався напружено-деформований стан конструкції. Проведено порівняння значень отриманих напружень з допустимими для застосовуваних матеріалів, на підставі чого було зроблено висновки щодо міцності конструкції при сейсмічному впливі. Результатом динамічного розрахунку стало визначення жорсткості конструкції. Порівняння отриманих значень напружень з допустимими для даного обладнання дозволило зробити висновок щодо його стійкості до сейсмічного впливу. Оцінку сейсмостійкості виконано на прикладі конденсатора парової турбіни К-1000-60/1500. Розрахунок на сейсмостійкість вказаного обладнання виконано при інтенсивності сейсмічного впливу 6 балів за шкалою MSK-64. В ході розв'язання поставленої задачі отримано результати розподілу напружень в корпусі та інших елементах конструкції конденсатора від дії навантажень під час нормальної експлуатації та проектного землетрусу. Розрахунок обладнання на сейсмостійкість виконано за допомогою методу скінченних елементів. Це дозволило подати суцільне тіло у вигляді сукупності окремих скінченних елементів, що взаємодіють між собою в скінченному числі вузлових точок. До цих точок прикладаються деякі зусилля взаємодії, що характеризують вплив розподілених внутрішніх напружень, прикладених уздовж реальних границь суміжних елементів. Для проведення такого розрахунку в пакеті CAD моделювання створено тривимірну модель. Отриману геометричну модель імпортовано в програмний комплекс, що дозволило істотно скоротити трудомісткість. Застосування розрахункового методу дозволяє значно знизити обсяг випробувань при підтвердженні сейсмостійкості обладнання. Отримано результати просторового складного напруженого стану конструкції конденсатора парової турбіни від дії під час нормальної експлуатації та проектного землетрусу.

Ключові слова*: турбіна, сейсмостійкість, напруження, землетрус, акселерограма, скінченний елемент, власна частота.*

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