Simulation of seismic reactions of an energy steam boiler

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Abstract. Energy boilers for seismic impacts are different from other objects. Their individual characteristics are associated with the frame construction and the boilers used pipes of great length. The most important parameter used in the calculation of seismic effects is the damp-ratio. The damp-ratio is different for pipes and frame, and this creates difficulties in performing calculations. The paper proposed a method for taking into account the difference of the damp-ratio and estimated the calculation error in the case of the use of the damp-ratio for the frame when calculating the entire boiler without taking into account the features of pipe damping. According to the results of calculations, the elements with the greatest deformations and the elements with the highest stresses in the metal are identified in the boiler structure.

1. Introduction
Seismic stability of energy facilities is the most important condition for ensuring safety and eliminating the effects of earthquakes. A feature of power boilers is their large size and frame arrangement with long pipes, hanging freely in the furnace or in the convection section of the boiler. With this design, the supporting elements of the boiler and the pipe are characterized by low natural vibration frequencies. Analyzing the frequency spectrum of oscillations during an earthquake, one can single out a multitude of frequencies coinciding with or close to the natural frequency of the boiler elements. This leads to resonance phenomena during seismic effects and is the main cause of the deformation or destruction of the boiler elements. The greatest deformations are observed in the boiler furnace and its lining.

In addition to the coincidence of the natural frequencies of the elements of the boiler with the frequency of external influences, the amplitude of oscillations depends on the damping characteristics - the damp-ratio. When modeling deformations under cyclic effects, the damp-ratio for different elements of the boiler should be different for each of them [1-2]. In NP-031-1 “Standards for designing seismic resistant nuclear power plants”, the damp-ratio for steel welded structures, to which the boiler frame belongs, is assumed to be 0.12, and for pipes – 0.06 [3]. The variety of pipe diameters, their lengths and ways of connecting with the boiler frame creates the problem of choosing the damp-ratio. To solve this problem, a finite element model of the BKZ-420-140 boiler has been developed. The modal analysis allowed us to distinguish the natural frequencies of the boiler tubes, for which the damp-ratio is assumed to be 0.06, and for the remaining frequencies characteristic of the frame elements and walls of the boiler, the damp-ratio is 0.12 [4-9]. To determine the influence of the damp-ratio, two groups of calculations were made: the damp-ratio was taken separately for pipes equal to 0.06 and for the frame equal to 0.12, the second calculation was made for the damp-ratio equal to 0.12 for all elements of the boiler.

The finite element model of the BKZ-420-140 boiler is shown in Figure 1.
Figure 1. Finite element model of steam boiler BKZ-420-140

2. Materials and Methods

The solution used is based on solving a dynamic problem of deformation of a model under the influence of an external cyclic impact with variable frequencies in a quasistatic form [10-19], which can be represented as an oscillator response with a frequency \( \omega_m \) to an impact given by the accelerogram \( \ddot{A}_0(t) \):

\[
\{S\}_m = [M]_m[D]_m W(\omega_m \xi_m)
\]

where: \( W(\omega_m \xi_m) \) - response seismic spectrum reading with attenuation \( \xi_m \) at the frequency \( \omega_m \), built for accelerogram \( \ddot{A}_0(t) \);

\( [D]_m \) - coefficient of influence, a constant value for the m-th form of oscillations of the calculated-dynamic model of construction;

\( \omega_m \) - own m-th oscillation frequency;

\( M \) - modal mass;

\( \phi_m \) - phase angle.

The solution uses an accelerogram, given there is a three-component effect on the finite element model (Figure 2).

The resulting internal forces from the effect of the calculated seismic forces are obtained by summing the vectors for all considered vibration modes. Modal analysis of the boiler model showed that the natural oscillations of pipes with a length of 3 to 35 m occur at a variety of frequencies with a value of up to 1 Hz. The natural frequencies of the various elements of the boiler frame are in the range from 3 to 30 Hz. Because the offset values for different own forms of each of the elements depend on the time point; the total calculated seismic deformations are determined by the superposition method in the course of dynamic analysis on the accelerogram effect by RMS summation:
Figure 2. Accelerogram 7 points
3. Results
Analysis of the accelerogram (Fig. 2) shows that the largest amplitudes are characteristic for a time from 2 to 4 seconds from the start of an earthquake. The maximum amplitudes of oscillations of the frame and the pipes of the boiler do not coincide in time with the accelerogram and the maximum strains occur in the range from 5 to 8-10 seconds. This confirms the resonant nature of the deformations. Fig. 3 shows the deformation shape of the boiler tube bundle.

![Deformation shape of the boiler tube bundle](image)

**Figure 3.** Pipe deformation at time points: a - 6.6 sec; b - 7.3 seconds (boiler frame is hidden), m

As can be seen from the figure, the greatest pipe deformations are observed in the lower and central parts of the bundles of screen tubes and superheater tubes. Maximum stresses are observed at the top of the tubes of the steam superheaters at the points of attachment. The zones of maximum stress are shown in fig. 4.
4. Discussion

Of greatest interest is the assessment of the impact on the result of taking into account the differences damp-ratio of various elements of the boiler. Figure 5 shows the results of two variants of calculating the strain from time to time. In the first version, the damp-ratio was set equal to 0.12 for the whole boiler, in the second version, the damp-ratio was set differentially and equal to 0.06 for pipes and 0.12 for the boiler frame.

The calculation for the second option was carried out in two stages. At the first stage, a modal analysis was performed and the natural vibration frequencies of the pipes were distinguished. At the second stage, the damp-ratio for the received frequencies was taken to be 0.06 and a seismic calculation was performed with these additions.

As can be seen from fig. 5, deformations occur synchronously with minimal differences for the first and second variants. Figure 6 shows the graph of the difference between the calculation results. At the first stage, small values of the damp-ratio for pipes are brought with a large relative deviations in a large direction. The deviation exceeds 20%. It is obvious that small values of damp-ratio determine a greater probability of oscillations, since damping occurs slowly. It should be noted that the absolute deformations at this stage are minimal.

In the range of 8-9 seconds, small damp-ratio values lead to the opposite effect, reducing the amplitude of deformations. The deviation is small and is about 6%. There are no obvious reasons for the decrease in the amplitude of deformations, but, as a working hypothesis, one can assume the influence of vibration interference. Because natural frequencies of oscillations of pipes are significantly different from the frequencies of the boiler frame, oscillations can occur in antiphase, mutually quenching each other.
Figure 5. Maximum deformations of pipes of the boiler BKZ-420-140 during seismic exposure

Figure 6. Difference of calculation results with a differentiated damp-ratio for the frame and pipes from the same damp-ratio for all elements of the boiler

5. Conclusion
Calculation of seismic reactions of an energy steam boiler using the BKZ-420-140 boiler as an example showed that the deformations of the boiler elements, and, first of all, pipes, can reach 0.25 m. The greatest stresses in the pipes during an earthquake will be at the top of the pipes of the steam
superheaters, which can lead to their destruction. Pipe deformations are also dangerous due to the high probability of mutual collisions, since at certain points in time, the amplitudes of oscillations exceed 0.2 m, and because of the difference in frequencies, oscillations of pipes can occur in antiphase.

Testing the influence of the differential damp-ratio designation for the boiler and pipe frame showed a significant increase in the complexity of the calculation due to the need to take into account a significant number of natural frequencies of pipe oscillations. The calculation error in the area of maximum deformations does not exceed 6%.

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