

Ensuring the seismic resistance of operated CHP buildings

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Abstract. The main structures of the engine room of the CHP are among the most responsible reinforced concrete structures, since during operation they are subjected to significant technological loads, including those not provided for by the project. One of the most significant impacts is seismic. During the long-term operation of the CHP, the building structures have experienced significant alternating loads. As a result, the thermal power plants built 45-60 years ago and currently in operation have a reduced level of seismic resistance. As recent events in Turkey have shown, ensuring the safe operation of power plants is a key task. However, new construction is expensive and not always justified, in this regard, the task is to ensure the seismic resistance of existing power plants in seismically hazardous areas.

Keywords: CHP, stress-strain state, through cracking, reinforcement of reinforced concrete floor and surrounding structures, composite materials, computational research, finite element method.

1 Introduction

During the design, construction and operation of CHPPs in the USSR, regulatory documents were in effect: "Standards and Rules for Construction in Seismic Areas" (SN 8-57) [1], "Design Standards. Construction in Seismic Areas" (SNiP II. A.12-62) [2], "Design Standards. Construction in seismic areas" (SNIP II-7-81) [3], which presents the design seismicity of areas. During the long period of CHPP operation, the building structures of the main buildings have undergone changes compared to the design prerequisites. Currently valid regulatory documents: "Code of Rules. Construction in seismic areas" (SP 14.13330.2018) [4] and "Seismic zoning of Russia" (OSR-2015- A, B) [5] contain instructions of increased seismicity for 1-2 points more than previous design seismicity.

Thus, cogeneration plants built 45-60 years ago and operating today have a reduced level of seismic resistance.

The variant of increase of seismic resistance of building structures of the operated TPP by means of reinforcement by composite materials and bringing in accordance with OSR-2015-A.B. is offered.

The main building of the TPP is a two-span industrial building of rectangular shape in the plan, consisting of four phases (Fig. 1).

The length of the building (in axes) - 290.0 m, the width of the building (in axes) - 49.0 m, the height of the building (from floor to bottom of the ceiling) - 16.2 ... 27.85 m.

The structural scheme of the main building of the CHPP is a frame building.

2 Methods

Visual and instrumental studies of the stress-strain state of the reinforced concrete structure of the machinery hall and surrounding structures were carried out using optical instruments (a reading microscope MPB-3), Schmidt's hammer to determine the strength of concrete structures, as well as the "unloading reinforcement" to determine the actual stresses in the reinforcement designs. The computational studies of the stress-strain state of reinforced concrete structures that have developed as a result of a load drop, as well as the design substantiation of the proposed solutions for strengthening damaged structures were carried out on the basis of spatial finite-element models. To enhance reinforced concrete floors and surrounding structures, it was proposed to use external reinforcement made of carbon composite tapes.

3 Description of structures

The soils at the base of the foundations are fresh, strongly fractured, dark gray andesite. The cracks are filled with sandy loam and landwaste. The normative load on the foundation soils is 6 kg/cm². The groundwater level is located at minus 2.74 m. Groundwater contains sulfuric acid salts and is aggressive for Portland cement concrete.

Foundations under the columns of the main building frame of the first phase are monolithic reinforced concrete slab type of concrete grade M200 (class B15) and made of a concrete preparation

200 mm thick of concrete grade M75. Depth of foundations - 3 m.

Columns - precast reinforced concrete, two-branch of concrete grade M300 (class B20). Step of the columns 6.0 m.

The rafter trusses are of steel, welded, trapezoidal shape with additional struts and spar system. The girders of the trusses, as well as struts and stands of the connecting lattice are made of paired rolled angles.

Cover slabs - precast reinforced concrete ribbed 6000×1500×300 mm.

The wall fence - prefabricated claydite concrete panels "PS" thickness of 250 mm. The roof is gable, soft with organized internal drainage.

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Columns - welded metal of VSSt3ps, constant-height through section, two-branch. Branches are made of composite and rolled I-beams, installed with 1410 mm separation. Connecting lattice struts between the branches of the columns are made of single equal flats rolled angles. The struts between the column branches are made of a single rolled channel.

The connecting trusses between the columns are spatial metal.

The rafter trusses are of steel, welded, trapezoidal shape with additional struts and spar system. The girders of the trusses, as well as the struts and the connecting lattice studs are

made of paired rolled angles. Horizontal ties on the upper and lower chords of trusses are crosswise, struts of horizontal ties are made of single rolled angles.

Cover slabs - precast reinforced concrete ribbed $6000 \times 1500 \times 300$ mm.

The wall fence - precast claydite concrete panels "PS" thickness of 250 mm.

The roof is gable, soft with organized internal drainage. Within the building, 80 mm thick foam concrete with a volumetric weight of 550 kg/m^3 is laid on the roof slabs.

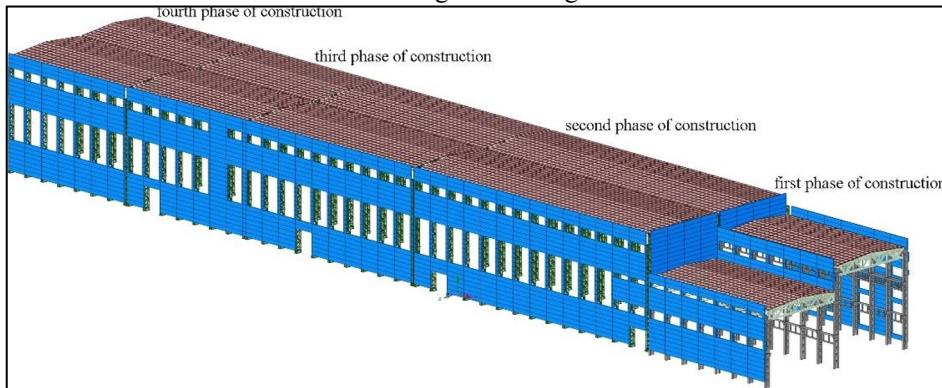


Fig. 1. Spatial model of the building with the order of erection

It should be noted that in the second and third phases of the TPP main building the foundations for the columns of the frame are monolithic reinforced concrete columns of M200 concrete (class B15) made on a concrete preparation of 200 mm thick made of M75 concrete; the depth of the foundation is 3.5 m. In the fourth phase of the building, the foundations for the columns of the building framework are monolithic reinforced concrete foundations made of M200 concrete (class B15) on a pile foundation. The depth of pile driving - 3.5...7 m.

4 Information about previous surveys

The following should be noted:

- Measured settlement of buildings and structures in absolute value of the average and maximum do not exceed the established tolerances.
- Deformation of the main body frame due to settlement does not exceed permissible values.
- Deformation of turbine generator foundations due to settlements does not exceed permissible values.
- Deformation of boiler unit foundations (due to settlement) does not exceed permissible values.

At the same time, further safe operation of the main building of the TPP is possible on limited parameters: until the work on strengthening the elements of columns and trusses is performed, do not allow the storage of building materials on the roofing and floor areas of the building, do not allow the suspension of technological equipment and use of building structures as stops and fasteners in the process of repair work.

The next stage of inspections of the technical condition of the reinforced concrete structures of the main building of the CHPP was carried out in 2022.

The analysis of the results was carried out according to GOST 31937-2011 [8], SP 13-102-2003 [9] "Rules of the inspection of the bearing building structures of the buildings and constructions" and other normative documents on the basis of which the technical condition of the building structures and their correspondence to the conditions of safe operation were determined. During the inspection, the building structures were inspected, in the beginning,

in the most stressed places with fixing of defects and damages, with determination of the nature and causes of their occurrence.

The main typical defects detected in the process of inspecting the roof slabs of the turbine hall are (Fig. 2):

1) Traces of leaks with leaching on reinforced concrete slabs of drainage gutters and roofing slabs, presented in the form of white stains on the surface of the slabs. This defect is caused by water filtration through concrete with gradual dissolution and washout of cement stone components. The water filtration is caused by a breach in the tightness of the roof.

2) Destruction of the protective layer of concrete with bare reinforcement on the shelves and ribs of reinforced concrete slabs of roofing and the bottom part of the reinforced concrete slabs of drainage gutters, the presence of cracks. Concrete deterioration is caused by corrosion of the reinforcement from water filtration through concrete.



Fig. 2. A - condition of reinforced concrete slabs of the roof of the turbine hall and drainage gutter slabs. B - crack in the structures of the turbine generator foundation at the place of binding the supporting columns with the reinforcing belt.

In accordance with the lists of defects identified as a result of inspections:

- 1) Traces of leaks with leaching were fixed in the area of 415 m²;
- 2) Fracture of the protective layer of concrete with bare reinforcement was recorded in the area of 75 m²;
- 3) The length of the cracks is 30 m.

It should be noted that the hazard category of defects and damages according to STO 70238424.27.140.026-2009 [8] defects and damages of local character, which in the subsequent development can have no effect on the main load-bearing structures of the building and the structure.

The main typical defects of load-bearing reinforced concrete columns detected in the process of inspections are:

- 1) Fracture and chipping of the protective layer of concrete on the faces and ribs of the columns.
- 2) Traces of leaks with leaching, presented in the form of spots of white plaque on the surface of the columns. This defect is caused by the filtration of water from precipitation through the concrete with a gradual dissolution and leaching of cement stone components.
- 3) Cracks with a width of opening up to 0.2 mm.

The average concrete strength of the engine hall and boiler hall columns, determined by the method of elastic rebound (Schmidt hammer) and the ultrasonic method is 31.2-32.6 MPa, which meets the requirements of the project (M300).

Inspections of the foundations of turbine generators established the formation of cracks in the area of the monolithic binding belt both in the joints of individual reinforcement cages (Fig. 2 B), and in the middle of the spans between individual columns, which is explained by insufficient rigidity of the joints. The width of crack opening in this area was fixed within 0.3 mm.

The strength of concrete determined by the method of elastic rebound (Schmidt hammer) and the ultrasonic method:

- 1) In the supporting columns of turbine generators - 26.8-27.3 MPa, which meets the requirements of the project (M200);
- 2) In the binding transom of turbine generators - 32.8 MPa, which provides the requirements of the project (M300)

5 Calculations of Phase I of the main building of the CHPP

5.1 Modeling technique

Calculations of the structural elements of the structure are made in accordance with SP16.13330.2017 [9] "Steel structures" and SP 63.13330.2018 [10] "Concrete and reinforced concrete structures."

In the calculation of structures, their structures and foundations is subject to verification of the following condition, which ensures the prevention of the onset of limiting states:

$$\gamma_{lc} F = \gamma_c R \quad (1)$$

In accordance with SP16.13330.2017 [9] "Steel structures. Revised edition of SNiP II-23-81*"

The forces acting in the structures were determined taking into account the calculations of the stress-strain state based on the spatial finite-element model of the structure with the base (Fig. 1).

Computational research on mathematical models is carried out by the iterative method of calculation, which uses a finite number of stages.

Figure 3 (a) shows a finite-element model of a part of the building of the main building of the first phase of construction with reinforced concrete columns and metal roof trusses.

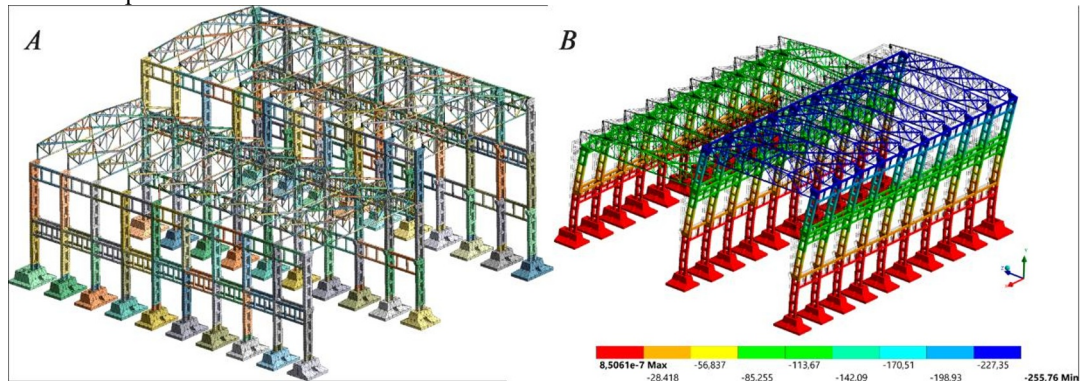


Fig. 3. A - Computational finite-element scheme of phase I; B - Seismic impact of 10 points. Horizontal displacements along axis Z, mm

5.2 Loads and impacts

Special P_s loads include seismic impacts. Calculation of structures on the limit states of the 1st and 2nd groups are performed taking into account the unfavorable combinations of loads or their corresponding forces.

Depending on the considered composition of loads:

– the main combinations of loads, consisting of permanent, long-lasting and short-lasting

$$C_m = P_d + (\Psi_{11} P_{11} + \Psi_{12} P_{12} + \Psi_{13} P_{13} + \dots) + (\Psi_{21} P_{21} + \Psi_{22} P_{22} + \Psi_{23} P_{23} + \dots) \quad (2)$$

– special combinations of loads consisting of permanent, long-lasting, short-lived and one of the special loads.

$$C_s = C_m + P_s \quad (3)$$

where C_m - is the load for the main combination;

C_s - load for a special combination;

$\Psi_{1i}(i=1,2,3,\dots)$ - combination coefficients for continuous loads;

$\Psi_{2i}(i=1,2,3,\dots)$ - coefficients of combination for short-term loads.

5.3 Calculation results for static loads, seismic and temperature impacts

Below are the results of computational studies, taking into account the seismic impact of 10 points, directed across the main building.

As can be seen from Figure 4 in the seismic calculation, the largest displacements have the top of the building. The results of computational studies in the form of horizontal displacements. Maximum horizontal displacement in the direction of axis Z under the seismic impact of 10 points was 255.76 mm. The maximum horizontal displacement occurs throughout the upper part of the building in the "B"- "D" axes.

Figure 4 shows the results of the calculation in the form of vertical stresses in reinforced concrete structures.

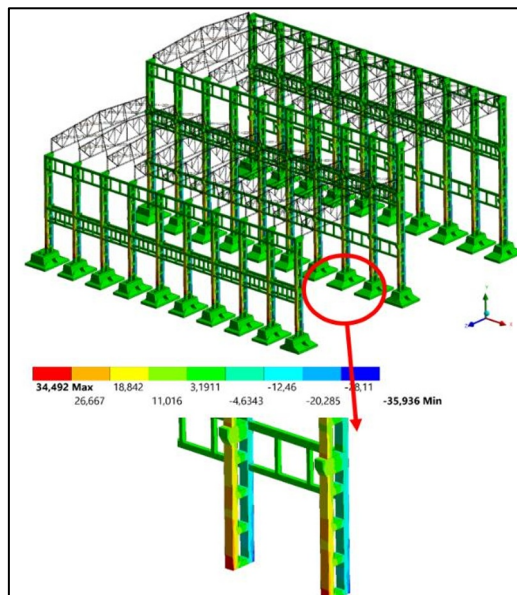


Fig. 4. Seismic impact of 10 points. Vertical stresses, MPa

The maximum vertical stresses, as seen in Figure 4, are 35.94 MPa and are located in the column's embedment in the foundation. We check the strength of reinforced concrete structures for this part of the structure by comparing the calculated reinforcement areas obtained with those actually installed.

The maximum design reinforcement for a seismic impact of 10 points is 31.04 cm².

According to the design drawings, the actual reinforcement of the column branch is 25.98 cm².

The results of comparison of design and actual reinforcement in a reinforced concrete column showed that the design reinforcement at seismic impact of 10 points is required more than actually installed. Reinforcement of the structure is required.

5.4 Results of calculation of structural reinforcement of the main building of phase I

The results of the calculation of the option of reinforcing the reinforced concrete columns of the main building of the first phase are presented.

The reinforcement option was chosen in the form of a system of external reinforcement and covering the reinforced concrete column with Carbon Wrap Tape-230/500 type.

Reinforcement of the reinforced concrete structure of the column in the calculation studies is taken from the bottom of the column to the height of 3.500 m.

Figure 5 shows the results of the calculation of the horizontal displacements of the reinforced concrete column, taking into account the system of external reinforcement.

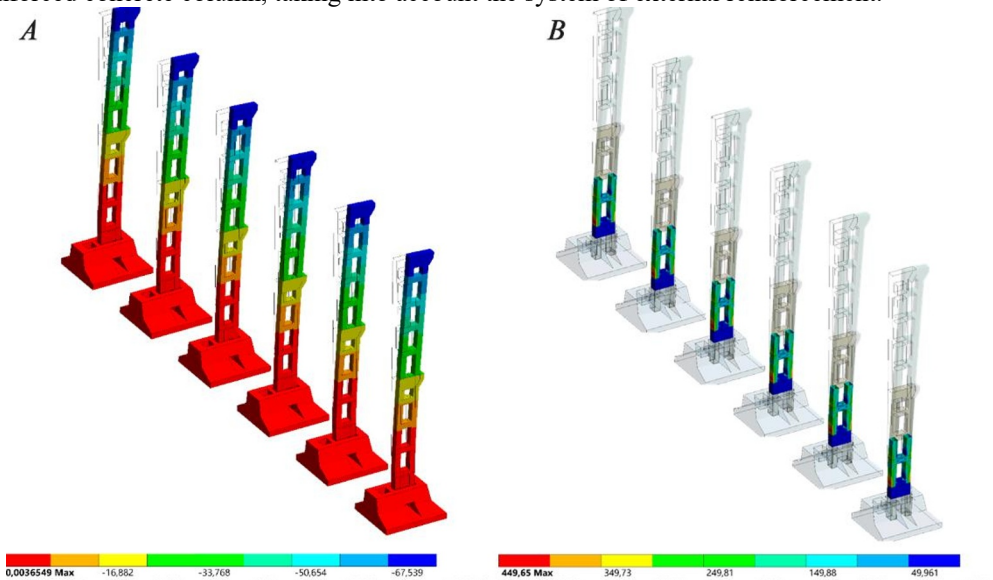


Fig. 5. Seismic impact of 10 points. A- Horizontal displacements, mm B - Equivalent stresses in the carbon tape, MPa

As can be seen from Figure 5 the maximum horizontal displacement of the top of the columns on the axis of "A" was 75.98 mm, and without the strengthening of horizontal displacement was 142.09 mm. Thus, the system of external reinforcement allowed to reduce the horizontal displacement under seismic action by 1.8 times. Maximum vertical stresses, as shown, are 22.00 MPa and are located in the column embedment in the foundation.

At the same time, the stress level in the column, taking into account the system of external reinforcement, decreased from 35.94 MPa to 22.00 MPa.

The strength of reinforced concrete structures is checked accordingly for this part of the structure by comparing the calculated reinforcement areas obtained with those actually installed.

The maximum design reinforcement at a seismic impact of 10 points, taking into account the system of external reinforcement is 13.45 cm^2 .

According to the design drawings, the actual reinforcement of the column branch is 25.98 cm^2 .

The maximum stress in the carbon tapes is 499.65 MPa and does not exceed the tensile strength of the tape (1000 MPa). The results of the calculation of the stress-strain state of the metal truss node under a seismic impact of 10 points are shown in Figures 6 (a) before amplification and Figures 6 (b) after strengthening.

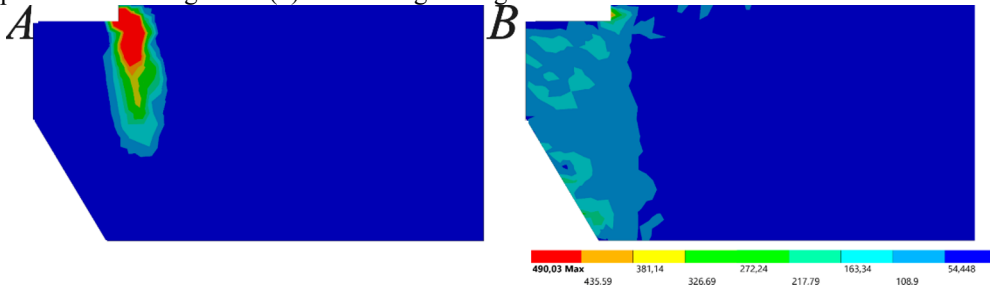


Fig. 6. Seismic impact of 10 points. A - Cracking in the cantilever part of the column, before amplification; B - Stresses in the reinforcement, MPa after strengthening

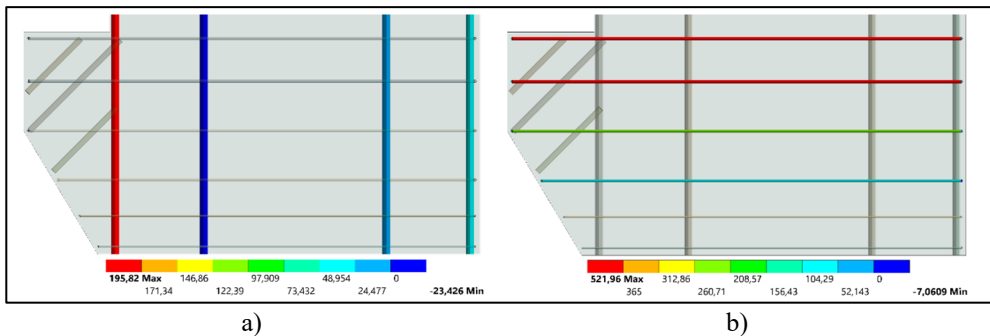


Fig. 7. Seismic impact of 10 points. a) - stresses in the vertical reinforcement of the column $\text{Ø}32 \text{ mm}$; b) - stresses in the horizontal reinforcement of the column $\text{Ø}12 \text{ mm}$

As can be seen from Figure 7 (a) the maximum tensile stresses in the reinforcement of 25 mm diameter under the seismic effects are 562.11 MPa, which is greater than the calculated resistance of the reinforcement of class A-II (280 MPa).

As can be seen from Figure 7 (b) the maximum tensile stresses in the rebar with a diameter of 12 mm under the seismic effects is 521.96 MPa, which is greater than the calculated resistance of the armature class A-II (280 MPa).

Thus, the attachment node of the metal truss to the reinforced concrete column does not meet the criteria of strength from seismic effects of 10 points. Reinforcement of the structure is required. Reinforcement is done with Carbon Wrap Tape-230/500. During the reinforcement, the maximum tensile stresses in the 25-mm diameter rebar under seismic action is 54.36 MPa, which does not exceed the design resistance of the reinforcement class A-II (280 MPa).

The maximum tensile stresses in the 12-mm diameter reinforcement under seismic effects is 110.26 MPa, which does not exceed the calculated resistance of the reinforcement class A-II (280MPa).

Stresses in the reinforcement are 490.03 MPa, and do not exceed the tensile strength of the tape (1000 MPa).

Thus, as a result of structural reinforcement, the structure can withstand a seismic impact of 10 points.

6 Conclusions

1) The examination and analysis of the results of inspections of reinforced concrete structures of the first stage of the building of the main cornice of the operating TPP have been carried out. Typical defects of load-bearing structures, cover and floor slabs, foundations of turbine generators were identified.

2) A set of calculations of the first stage of the building on the action of a complex of loads and impacts: static, thermal and seismic, taking into account the defects of reinforced concrete structures established as a result of long-term operation.

3) The application of composite materials for reinforcement of bearing structures by means of the external reinforcement allows providing seismic resistance of the construction up to 10 points. Also application of composite materials allows to provide seismic resistance of joints: prefabricated floor slabs, prefabricated wall panels, etc.

References

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