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VARIANTS OF STRENGTHENING OF SHELLS OF REINFORCED CONCRETE COOLING TOWERS DEPENDING ON CONSTRUCTIONAL FEATURES AND ACTUAL TECHNICAL CONDITION

Introduction

The experience of construction shows that the absolute quality without exception of all high-rise buildings is almost impossible to achieve. This is confirmed by the analysis of the technical conditions of tall buildings in their thorough inspection. Unfortunately, a thorough examination of such structures is usually not carried out, which can be compared to the following technical conditions of its elements. Therefore, in almost all cases, the inspection results are compared with the “ideal” project condition, provided that the project does not allow defects that caused the damage found during the process of exploitation or inspection of buildings [1]. Serviceability and durability of structures are known to depend not only on the regulations [2], the designer, but also on the manufacturers of materials, construction suppliers, installers, builders and operators.

The choice of the design scheme of buildings is not regulated by any documents. By choosing a particular scheme, the designer thereby determines the level of “safety circuit” of the future building in general, regardless of the serviceability of each element. In cases where the magnitude of possible external loads and actions to set accurately is not possible for some elements of the building, the designer seeks to provide its enhanced “design reliability”.

A thorough complex inspection of the technical condition of structural elements of existing high-rise buildings is an important area of research, because the very subject of the research is already built. Collection and analysis of survey materials make it possible to justify the development of more sophisticated design solutions and the choice of more rational design schemes of high-rise buildings [3, 4].

The totality of the obtained material will provide the basis for the development of the clarified payment methods and as a result - the improvement of the regulations that cover: stages, methods of research, processing of the results, and study, the search of options of possible technical solutions for the design and strengthening of elements of high-rise buildings that will provide long-term and reliable operation [2].

In order to prevent simple overlapping of elements during strengthening and thus create a solid construction, the designer has to imagine the whole picture of the construction and the subsequent operation, and consider various design features and the actual technical condition of this design.

1. The analysis of recent research and publications

Cooling tower is a structure (equipment) for cooling of large quantities of water by directed flow of air. Depending on the air supply variant, cooling towers are fan, tower and open (atmospheric). To cool the circulating water of the circulating systems of the energy companies (CHP, NPP) cooling towers are used (Fig. 1), which can be as high as 200 m. Depending on the material of the main load-bearing structures, cooling towers can be ventilator, tower or reinforced concrete.

a)

b)

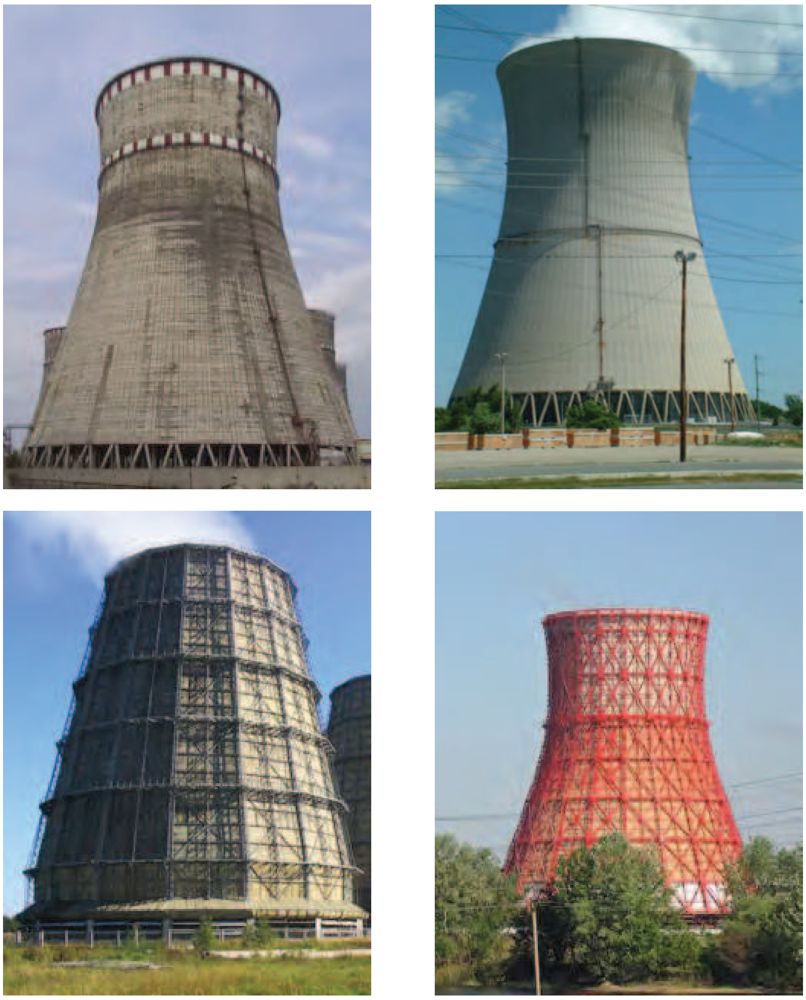

Fig. 1. Cooling towers: a) reinforced concrete, b) metal

The experience of the usage of the tower structures shows that the most durable and economical cooling towers are made of reinforced concrete [5-8]. Typically, the shells of such structures are performed monolithic, of hyperboloid shape. However, the construction of thin monolithic reinforced concrete shells is accompanied by complex organization and low industrialization of work, that is why some countries have begun to erect prefabricated reinforced concrete shells [5].

According to regulations, the term of usage of the cooling towers is set for 40 years [2]. The extension of the usage term above the set one is permitted only after inspection and evaluation of technical condition of buildings. In this case, specific operating conditions or requirements concerning the measures to prevent overloads and more should be indicated.

2. The aim and subject of the research

This paper deals with some implemented in practice building approaches to the development options for strengthening of shells of reinforced concrete cooling towers, depending on the identified test of their technical condition and design features of shells.

The subjects of the research and analysis are: prefabricated reinforced concrete ribbed biconical shell of the cooling tower #4 on the Darnytska CHP in Kiev, Ukraine and the monolithic reinforced concrete shell of the cooling tower #2 of the Adamow power station in Poland. An interesting coincidence on the term of usage, about 40 years, is registered.

Cooling tower #4 on the Darnytska CHP is the first and only prefabricated ribbed reinforced concrete cooling biconical tower in the territory of the Soviet Union, which was designed by N.N. Dotsenko. The height of the cooling tower is 55.1 m, the maximum diameter is 49 m, the area of irrigation is 1600 m^2. Its shell is mounted from 400 concrete panels (10 tiers of 40 panels in each tier) of the trapezoidal (in the background) form, of caisson type, the length 5.2 m and the variable width [5]. Given the uniqueness of the structure, the experience of the technical operational supervision and the strengthening of the structures of this type is unavailable.

Cooling tower #2 of the Adamow power station in Poland is a monolithic reinforced concrete cooling tower with hyperboloid shell of rotation, the irrigation area of which is 1600 m^2. Full height of the cooling tower is 90 m, maximum diameter - 66.8 m.

3. The presentation of the basic material

Prefabricated reinforced concrete cooling tower #4 on the Darnytska CHP in Kiev, Ukraine

The cooling tower was built in 1961, and in 1996 it stopped working. After years without operation period in 2003, the research and design firm “Rekonstrproekt” with the participation of the author, made a full comprehensive examination of the object, the purpose of which was to evaluate the technical condition of all its structural elements.

From the conducted research of the prefabricated reinforced concrete shell of the cooling towers the following results should be displayed:

– the shell over the existing operating load is in a poor technical condition (not applicable to normal operation). The most important hazard of its static work is the loss of adhesion of concrete with armature with decreasing of the area of section of the concrete of horizontal ribs to 25%. Working armature in the horizontal ribs of the panels as a result of corrosion lost from 24% to 80% of the area (Fig. 2);
– from the analysis of the calculations it is established that in winter the temperature technological load causes the appearance of significant longitudinal efforts of stretching in the horizontal ribs that are not considered in the design of this building. These efforts are due to characteristics of the temperature fields in the cross-section of the ribs and the wall of panels, at which the temperature deformations of the thermal expansion deformation in the wall of panels in the direction along the rib are larger than the corresponding deformations in the rib;
– it is necessary to do a major repair of shell reinforcement in order to provide the safety of its further reliable operation.

a) b)

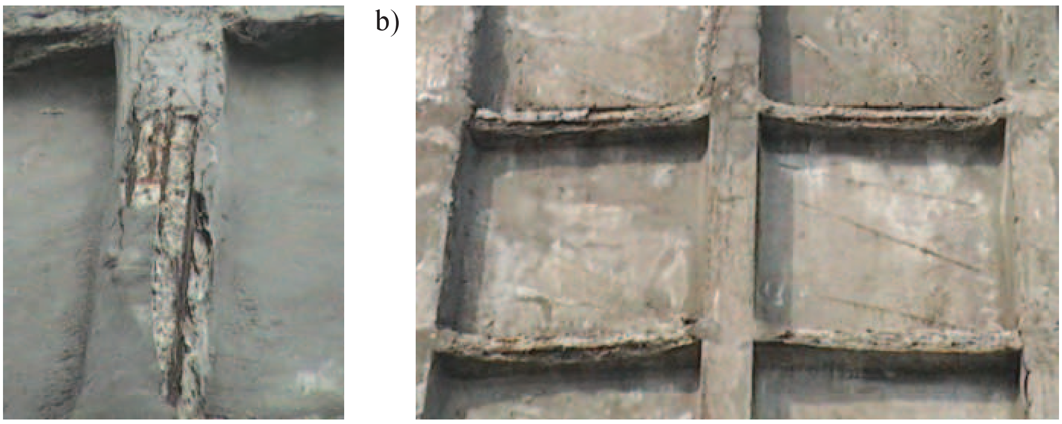

Fig. 2. Some defects in the shell of the cooling tower of the Darnyts'ka CHP:
a) corrosion of armature of panel on the vertical ribs, b) corrosion
of armature and destruction of the horizontal ribs

In connection with the above, in 2003, with the author, a technical project of the repair and strengthning of the shell of cooling tower was developed.

The technology of repair and strengthening used the materials produced by Sika to protect against concrete degradation and corrosion of armature and the metal elements of embedded parts. In addition to the typical design repairs there has been proposed a design solution with the introduction of a new ring of the formely prestressed armature, instead of the present one covered by corrosion, for fixation and reduction of vertical crack formations in the concrete of panels and vertical joints between them. This enhancement is provided by seven tiers of butt ribs of panels and on two middle ribs of panels of the first tier (Fig. 3).

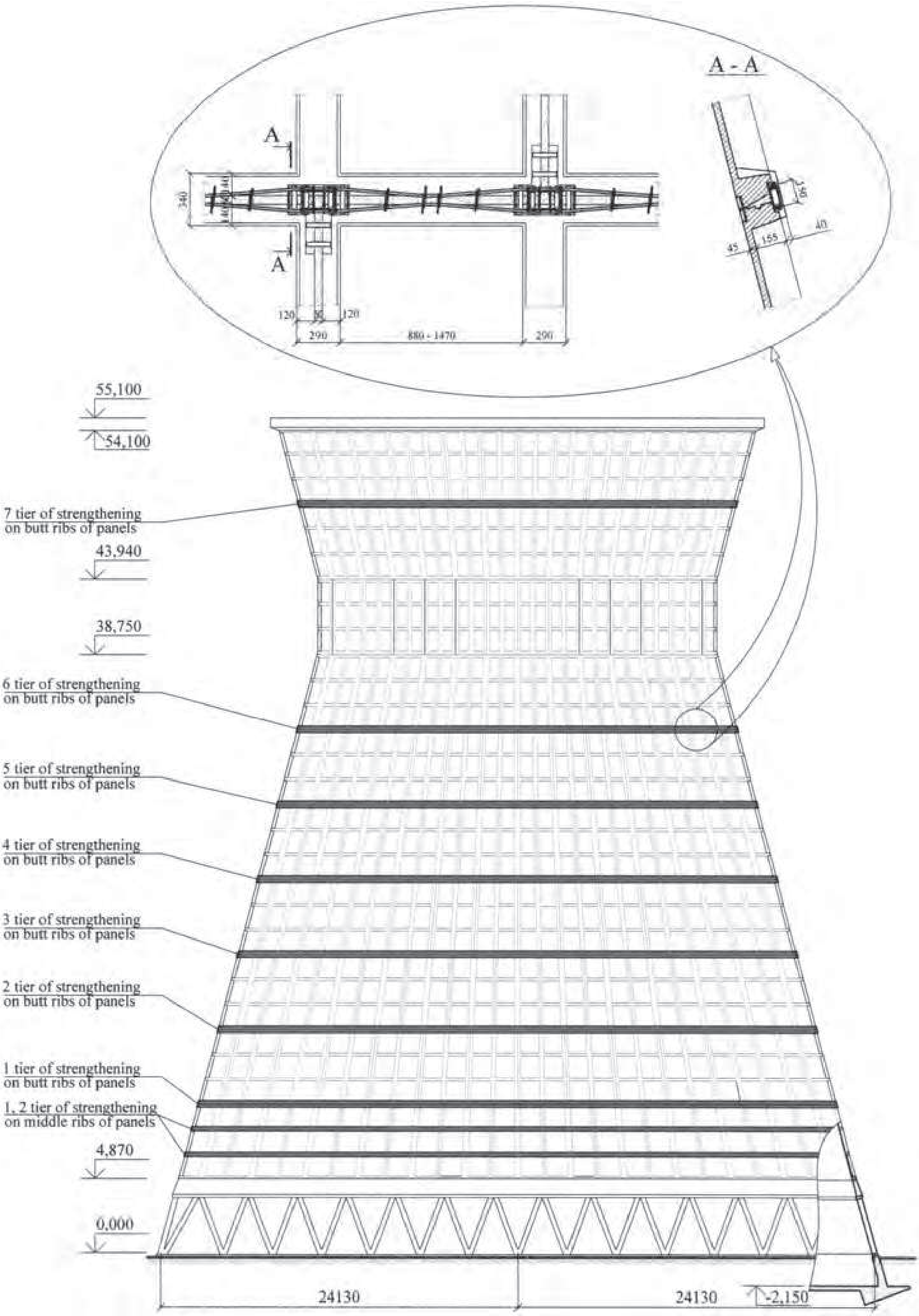

Fig. 3. The storeys of strengthening the horizontal ribs of precast reinforced concrete panels of cooling tower shell by prestressed ring armature

The technology of arrangement of strengthening included: fixation of a new ring of armature (ϕ14, ϕ16 A-III) to the formerly cleaned and reinforced embedded parts and connecting overlays for docking panels (Fig. 4a), a further tension of a new ring armature and its fixation by the cross clamps (Fig. 4b). Finally, after the establishment of the new elements of strengthening and their protection of a new ring of prestressed armature, existing and additional armature of strengthening installed to strengthen or replace the existing one, the designing of these areas on the perimeter of the shell was conducted (Figs. 5, 6).

The cooling tower after strengthening and repair was put into operation in 2004.

Monolithic reinforced concrete cooling tower #2 of the power plant Adamow in Poland

The cooling tower was built in 1962. In 2001 a complex examination of the cooling tower was made, the purpose of which was technical evaluation of the designs. The results are shown in the work [7], which are as follows:

– the cooling tower as a whole is in a poor technical condition;
– the technical condition of the shell can be evaluated as to the pre-emergency, which means that in the case of critical loads there is a real danger of its destruction;
– the major repairs of the shell strengthening for providing of the necessary for the cooling tower operating strength for the safety of its further operation need to be done.

Taking into account all the above-mentioned, in 2004 the technical project of repair and strengthening of cooling tower was developed. This project provides the performance of strengthening in the area of the biggest damages of the surface of the cooling tower shell (from 37 to 45 cycles of concreting around its whole perimeter).

Two variants of performance of shell strengthening were developed.

a) b)

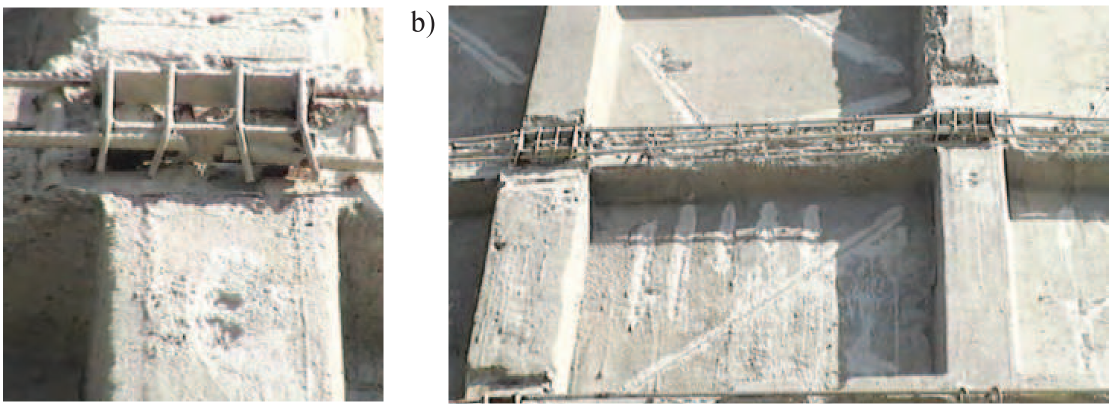

Fig. 4. The process of strengthening performance of horizontal ribs of panels: a) fixation of ring armature on reinforced embedded parts of panels, b) between the embedded parts prestressed reinforcing rods are connected by clamps and fixed to the armature of horizontal ribs

Fig. 5. Prefabricated concrete cooling tower of Darnyts'ka CHP after reconstruction

Fig. 6. The outer surface of the shell of the cooling tower during its repair and strengthening of the prestressed armature bars within additional horizontal ribs for stiffness

In the first case, the authors of the work [7] consider the strengthening of cooling tower shell by reinforced concrete ribs on the outside. The proposed scheme of strengthening performance consists of 3 parallel horizontal ribs and 23 ribs that are perpendicular to the horizontal ribs (Fig. 7). These ribs form a regular exterior reinforced concrete grill, which is involved in the joint operation with crosscut of the concrete of the shell.

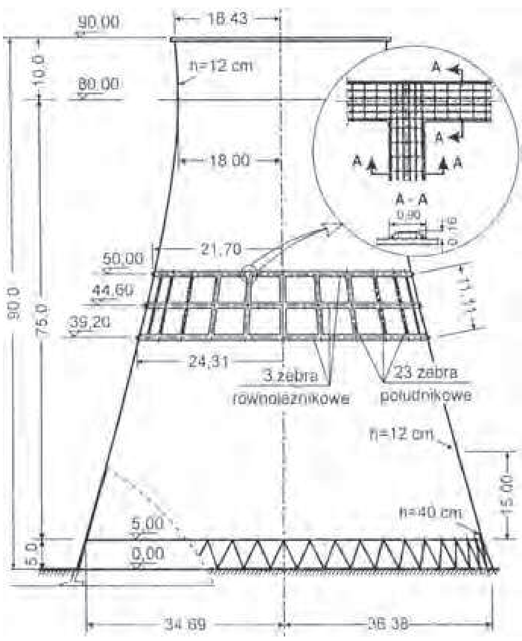

Fig. 7. The strengthening of the cooling tower shell by reinforced concrete ribs - the first variant [9]

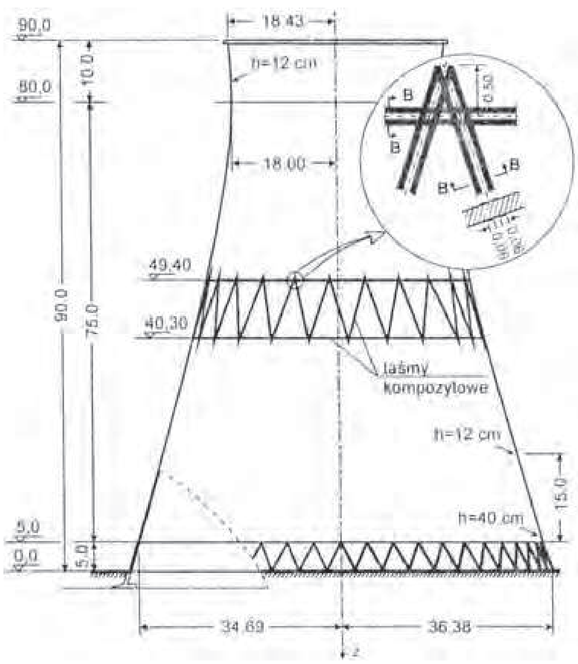

Fig. 8. The strengthening of cooling tower shell by composite tapes - the second variant [9]

Strengthening of a shell of cooling tower using reinforced concrete ribs was made before in Poland on cooling towers #2 and №8 of the power station Turoszow [8] and on the cooling tower #5 of the power station Adamow [6]. In these reinforcements ribs work as self-supporting constructions with large transverse stiffness. In contrast, the reinforcement from the system of concrete ribs, proposed by the authors of work [7], starts operation together with a cooling tower shell.

The second variant of the reinforcement lied in an arrangement of composite tapes produced by the company Sika, which are glued on the inner and outer membrane surface of the cooling towers (Fig. 8). The additional reinforcement of concrete shell by the composite tapes should serve as the main reinforcement. In this way, the composite tapes should be placed one in front of the other from both sides of the cooling tower shell.

The analysis of the suitability of use of the optimal from the two ways of shell reinforcement, discussed in the work [7], included the following parameters:

– the ensuring of the bearing capacity of construction;
– the technological conditions of the reinforcement fulfillment;
– the durability of operation of enhanced construction;
– the cost of enhancement fulfillment;
– the reliability of the enhanced construction work.

The calculations [6] have shown that the proposed reinforcements increase the carrying capacity of the cooling tower shell surface to 10÷15%. Slightly larger bearing capacity of shell surface is achieved when composite tapes are used to reinforce, but which should be installed on the inner and outer surfaces of the shell.

The technology of reinforcement fulfillment in two versions is different.

The process of shell reinforcement fulfillment in the first version using reinforced concrete ribs is difficult and time-consuming. Traditionally, such works are performed from the hanging pipes. The list of works of reinforcement, which should be done is rather extensive. The technological breaks are necessary because the scope of works is divided into a large number of catches. The difficulties of transporting of materials to the working points. The features of the reinforcement works influence on their performance term and cost.

With qualitative performance of works of strengthening the shell by reinforced concrete ribs, the ribs remain monolithically bound with shell.

The elimination of possible damages of reinforced concrete ribs of reinforcement, almost exclusively from weather influences, will be done with the whole shell on its outside surface.

In the second way the reinforcement should be done with the implementation of Sika Carbodur S614 tapes with width of 60 mm and thickness of 1.4 mm. The tapes should be glued on in pairs stick on the inner and outer surfaces of the shell in parallel circular perimeters of shell at a distance 12 sm between the axes of tapes, with Sika Dur 30 glue.

The duration of placement of ribbons is slight. All works are traditionally performed from cradles. The technology does not provide for mandatory breaks in the performance of work. Glue is gaining strength in 24 hours. In addition, the protection of tapes should be done from the internal technological and external weather conditions.

In case of defective foundation and inobservance of the technology of gluing tapes peeling off from their base may occur. Such damages are easy to notice and eliminate by re-gluing of tapes to the base. To eliminate this type of damage, the operation of cooling tower should be stopped on the inner surface of the shell.

The re-bonding of tapes on defective parts to the base of the inner or outer surfaces can change the stress state in the shell.

The comparing of cost for the performance of strengthening showed that during the performance of reinforcement by reinforced concrete ribs almost twice as expensive for the performance of shell reinforcement by composite tapes [9].

A comparative analysis of the two versions shows that the strengthening by system of composite tapes is the best technical solution in comparison with the arranging the system of reinforced concrete ribs, which are characterized by the shorter term of performance, lower cost, easier control of quality of works performance.

The arguments that are against the use of composite tapes is that they had been used in cooling towers not that often, especially on the inner surface of the shells. In the case of defective foundation and inobservance of technology in the arrangement of strengthening tapes peeling off from their base may occur. To eliminate this type of damage, the operation of cooling tower should be stopped.

To ensure the durability and reliability of the operation the strengthening cooling tower's casing was made in 2004 by a system of reinforced concrete ribs on the outside of the cooling tower casing.

Conclusions

1. Throughout the period of usage of the cooling tower (during the operation) it is necessary to carry out the scientific and technical support, since the poor technical state of its structures can be reasonably evaluated only by analyzing the results of a thorough complex examination and testing calculation of its structural elements.
2. When developing the strengthening projects of the shells of cooling towers the following things should be taken into account: their design features, the nature of their actual technical condition considering the distribution of the strength characteristics of concrete and the condition of armature on specific working sections, the nature of the spatial work of the shell of the cooling tower considering the state of the supporting colonnade, the parameters of which can significantly affect the performance of the shell.
3. The ten-year operation of the cooling tower number 4 of the Darnyts'ka CHP and the nine-year operation of the cooling tower #2 of the Adamow power plant, after strengthening of their shells with reinforced concrete belts of different

types (without and with prestressing armature belts) and repair of concrete surfaces of shells with Sika materials, showed the consistency of the adopted design and technological solutions.

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Abstract

The article provides design solutions of strengthening of reinforced concrete shells of the cooling towers with the usage of conventional and prestressed outer reinforced concrete ribs and composite materials, which are applied to actual objects in Ukraine and Poland.

Keywords: reinforced concrete, cooling towers, composites, prestressed constructions

Opcje wzmocnienia powłok żelbetowych chłodni kominowych w zależności od cech konstrukcyjnych i rzeczywistego stanu technicznego

Streszczenie

Przedstawiono warianty rozwiązań konstrukcyjnych wzmocnienia powłok żelbetowych chłodni kominowych z wykorzystaniem wstępnie sprężonych i zwykłych zewnętrznych żelbetowych żeber lub z materiałów kompozytowych, które są stosowane na rzeczywistych obiektach Ukrainy i Polski.

Słowa kluczowe: żelbet, chłodnie kominowe, konstrukcje sprężone, kompozyty