The use of long-span coating plates in case of reconstruction of “wet” spent nuclear fuel storage facilities

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Abstract. Spent nuclear fuel is one of the most dangerous threats on Earth. Its storage is carried out in various facilities, which include stand-alone “wet” storage facilities for spent nuclear fuel (SNFS). Such storage facilities were designed and built decades ago, when there were no industry requirements for accounting for extreme external impacts. Given the design features of the “wet” SNFS, in the event of their reconstruction it is advisable to consider the possibility of replacing the frame part of the structures with monolithic reinforced concrete elements that can withstand earthquakes and other effects of the required intensity.

1. Introduction

High potential hazard nuclear fuel cycle facilities include spent nuclear fuel storage facilities. Accidents at that facilities can lead to the release of large amounts of radioactive substances into the environment [1-5].

“Wet” SNFSs were designed decades ago when there were no modern requirements for taking into account extreme external impacts. For this reason, SNFS pools were closed, as a rule, with a relatively light and flexible frame, consisting of reinforced concrete columns rigidly embedded in the tank walls and articulated adjoining trusses [6] (figure1).

Figure 1. Cross section of "wet" SNFS.
Obviously, such a design is not able to meet the requirements of modern regulatory documents. At the same time, there is the issue of extending the life of the type of storage in question. When extending the service life, one of the main tasks is to ensure the bearing capacity of building structures under external impacts of greater intensity than were accepted at the time of design. Since the most vulnerable part of the objects under consideration is the long-span frame part [7], located directly above the exposure pools, it is proposed to consider the possibility of replacing it with monolithic reinforced concrete structures that meet the requirements of modern regulatory documents.

2. Methods
At the first stage of the study, calculations were made for a large-span coating plate and the external walls of the wet spent nuclear fuel storage facility during an earthquake and other extreme external impacts [8]. The calculation took into account:
- an earthquake with an intensity of 7 points on the MSK-64 scale (linear spectral theory);
- air shock wave with a front pressure of at least 10 kPa, compression phase time up to 1 s (quasi-static);
- impact of an aircraft weighing at least 5 tons (quasi-static).

Using SCAD Office [9] a rectangular plan model was created, depicting structures above the central hall of SNFS. Dimensions in the plan are assigned 40 x 20 m, height 15 m. (figure 2). At the level of the lower nodes of the design scheme, a rigid termination is adopted. Wall and coating thickness - 500 mm.

Figure 2. General view of the design scheme.

Using the finite element method according to the methodology [10], the selection of reinforcement was performed for the above effects. Concrete class B25, reinforcement class A400 were taken into account.

3. Results and discussions
Taking into account the considered effects, the reinforcement of the construction described above was selected. For comparison, the results of calculation of the reinforcement of the structure under load from its own weight are also given.

When calculating the load from its own weight from the condition of safety of the reinforcement, the crack opening width was limited: 0.3 mm for long opening and 0.4 mm for short. When calculating for extreme impacts, the crack opening width was not limited.

Calculation of its own weight showed that the largest areas required for the calculation of the longitudinal reinforcement are located on the surface of the structure, in the transverse direction. Both in the support and in the span zone of the plate, it is required to install reinforcing bars with a diameter of 32 mm with a pitch of 200 mm (figure 3).
Thus, even without taking into account any additional impacts, the considered construction requires substantial reinforcement.

Below are the results of the maximum reinforcement of structures taking into account extreme external impacts (figure 4).

To ensure the strength of such a large-span coating under the action of a load of only its own weight, it is necessary to reinforce with a grid with a cell of 200x200 mm by reinforcing rods with a diameter of 32 mm, which is already an essential indicator. At the same time, ensuring proper reinforcement under extreme conditions becomes problematic. For example, in the lower zone of the slab with a step of 200 mm, it is required to place 3 rows of reinforcing bars with a diameter of 40 mm. Obviously, it is irrational to reinforce the structure in this way, and with even larger spans, in principle, it becomes impossible. Other design decisions need to be considered.

The most obvious way to add extra rigidity to the coating is to install stiffeners. Consider the option of installing ribs with a thickness of 0.5 m, a height of 1.5 m, in increments of 2.5 m.

As a result of the calculation of the coating plate, acceptable numerical values of the areas of working reinforcement were obtained, which are quite possible to implement. The maximum diameter of the rods was 36 mm with a pitch of 200 mm.

Despite the acceptable results of the design reinforcement in the coating plate, significant areas of working reinforcement were obtained in the stiffeners. Designing such a design is irrational. (figure 5)

Another version of the coating plate was considered, consisting of two plates, between which stiffeners were installed with a step of 5 m. The thickness of the plates and ribs was adopted 400 mm, the height of the ribs, as in the previous case, was 1.5 m, the step of the ribs was 5 m (figure 6).

When using a double coating, even taking into account a decrease in the thickness of the structural elements, the acceptable area of the working reinforcement of both ribs and plates was obtained by calculation (figures 7; 8).

The maximum reinforcement of the bottom plate obtained by calculation is the rods with a pitch of 200 mm with a diameter of 28, 22, 40, and 36 mm for directions a, b, c, and d, respectively.

4. Conclusion
Thus, we can conclude that to ensure seismic stability, as well as the stability of the "wet" spent nuclear fuel storage facilities to other extreme external impacts, in the case of their reconstruction, it is advisable to use a coating and external walls, consisting of two plates and ribs between them.
Figure 4. The results of the longitudinal reinforcement calculation of building structures: a — lower coating reinforcement and reinforcement on the inside of the wall in the direction along the building; b - lower reinforcement of the coating and reinforcement on the inner side of the wall in the direction across the building; c - upper reinforcement in the direction of the coating across the building (cm² / m).

Figure 5. The longitudinal reinforcement required by calculation on one of the sides of the rib (on the second side, the reinforcement is symmetrical; cm² / m).

Figure 6. Double slab longitudinal section.

Figure 7. The longitudinal reinforcement required by calculation on one of the sides of the rib (on the second side, the reinforcement is symmetrical; cm² / m).
Figure 8. The calculation results of the upper double-coated slab with stiffeners in increments of 5 m: a - bottom reinforcement in the longitudinal direction; b - upper reinforcement in the longitudinal direction; c - lower reinforcement in the transverse direction; d - upper reinforcement in the transverse direction.

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