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A limit load analysis of the spent fuel storage pool structures of RBMK - 1500 reactors

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ABSTRACT: Presented is a mathematical stress analysis model using ALGOR computer program of the Ignalina NPP facilities where the hermetic containers CASTOR RBMK will be located. Analysis of the model provides resultant stresses caused by free falling container with spent fuel. The results yield wall deflections and peak stresses in the reinforcing bars of the structure, which maintains the integrity of these facilities of the Ignalina NPP. They indicate excessive deflections of the walls and stresses in reinforced concrete.

1. INTRODUCTION

It is important to maintain safe environmental work conditions at the Ignalina NPP while transporting spent nuclear fuel. The problem of storage of the spent nuclear fuel is solved by the use of hermetic containers, which provide stability to mechanical and thermochemical effects. These containers are placed in open or closed platforms for storage, in underground storehouses, etc. From ecological point of view for reliable long-term storage of the spent fuel in modern containers it is considered that at any time it should be possible to inspect the contents of the container and the radiological conditions of the environment. The spent nuclear fuel elements are placed by special manipulators into the containers. Then they are transported to temporary nuclear fuel pools. From here the containers should be transported to the location of long-term storage. The containers in question are the so-called CASTOR RBMK containers, designed by GNB.

For transportation of the container, the following information and work conditions are provided: the weight of the container with spent nuclear fuel is more than 80 tons, it could be lifted as high as 25 m and subsequently loaded to the pool with a depth of 12 m. The present transportation process has pitfalls and its safety is being questioned. During lifting of the container into the shipping shaft and loading it into the pool of compartment 338/1, the elevating devices used for transportation of the container could be damaged. The pool below the container could be destroyed, because of an accidental release of the container. The container itself could also be damaged. Catastrophical consequences would then be expected because of subsequent distribution of the radioactive substances to the environment.

The transportation route of the container from the reactor to the compartment 338/1 for storage was established for safety studies because of an accidental fall of the container in mind. The possibility to use the shock-absorber (Figure 1) at the base for this purpose was calculated, in case the container would drop from an elevation of 25.20 m to an elevation of 13.00 m, or from an elevation of 25.20 m to a small-sized area with an elevation of 17.00 m, or from an elevation of 19.70 m to a depth with an elevation of 13.00 m.

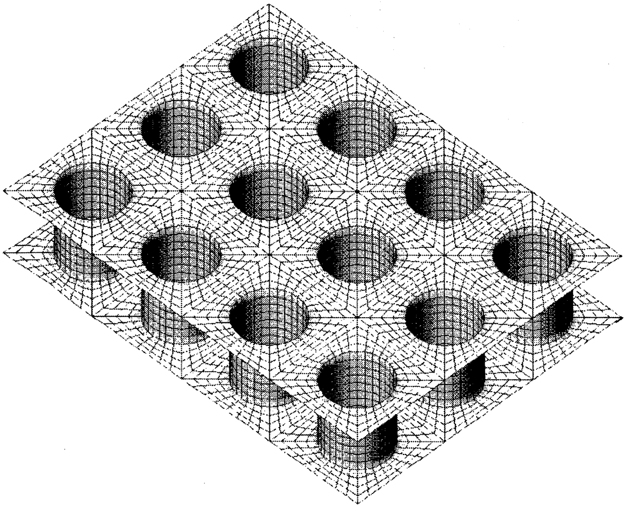


Figure 1. View of the shock-absorber

For this purpose the theory of strength of materials, structural mechanics, theory of plasticity, as well as the finite element method [1] used for the calculations. For the evaluation of the ultimate loads on the walls and the floors, some of the previous models are applied: the use of allowable stresses, those of ultimate conditions, as well as the finite element models.

2. THE FINITE ELEMENT MODEL OF RECTILINEAR COMPARTMENTS

The evaluation of the Ignalina NPP structure was conducted using finite element analysis ALGOR system. Because of the complicated configuration of the construction, the components - separate compartments - were simulated. Then, these were combined into a composite model and groups of compartments or individual compartments were analysed. Figure 2 presents the composite of the finite element model of the compartments taken into consideration.

The calculations were performed in several stages. In the first stage the compartments 338/1, 174, 337/1, 337/2, 339/1, and 339/2 were simulated and the strength analysis of reinforced concrete model for the determination of the most critical locations were conducted. After that, analysis of the more severely loaded floors and walls of the listed compartments were performed. Alongside with the finite element calculations, a check of design basis by means of accepted techniques [2,3,4] was made for allowable stresses and ultimate loads.

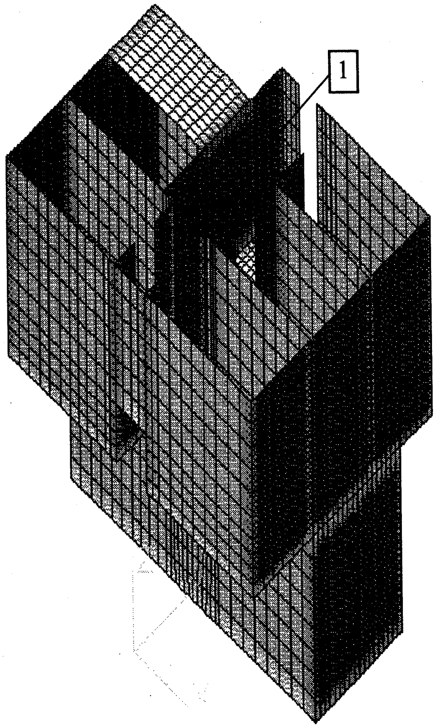


Figure 2.The general model of the compartments

Analysis of the dynamic loads of impact of the container on the floors and walls in compartments 174 and 338/1 was conducted by using of plate finite elements. The plate sandwich element, consisting of several layers of orthotropic materials was used. More details of the reinforced concrete design simulations was described in [5].

The arrangement of reinforcement, calculation of reinforcement layer thickness are presented in [5]. The load-carrying ability of thin steel liners in bending and stretching, while part of the walls, are not taken into account.

3. THE FINITE ELEMENT ANALYSIS UTILISING STATIC LOADS

The results of these investigations show the structural deformation and stress distribution from the applied loads. If under action of the loads from impact, the reinforcements undergo plastic deformation, the apparent cracking in concrete can extend to the inside walls. The internal surface layer of structures remains intact, until the membrane loading begins, when the section is entirely subjected to the action of tension. It can take place only after the rupture of the reinforcement layers. For more precise evaluations of strength of the heaviest loaded compartments, it is possible to use the non-linear deformation model. The stresses in reinforcements above the yield limit can lead to local damages of the structure.

4. VALUATION OF LOAD SUPPLEMENT DUE TO DYNAMIC EFFECT

Practical stress analysis shows [2], that dynamic loads cause much more deformation of than do static loads. The dynamic modulus of elasticity of concrete changes stress from zero to maximum for small periods of time during dynamic loading. For reinforced concrete elements it is possible to assume it to be constant and equal to the initial modulus of elasticity.

It is also important to keep in mind the massive character of the structures under consideration, the weight of which may be as much as 40-50 tons. This too increases the inertial resistance of the structures. On the basis mentioned, it is asserted, that the analysis assuming static loading is conservative.

5. RESULTS

The most severe accident occurs due to the free fall of the CASTOR RBMK container to the pool (Marking 1 in Figure 2) during transportation. It is paramount that cracks do not form in the floor, because of radioactive water in this pool. The model for finite element analysis of this pool is shown in Figure 3.

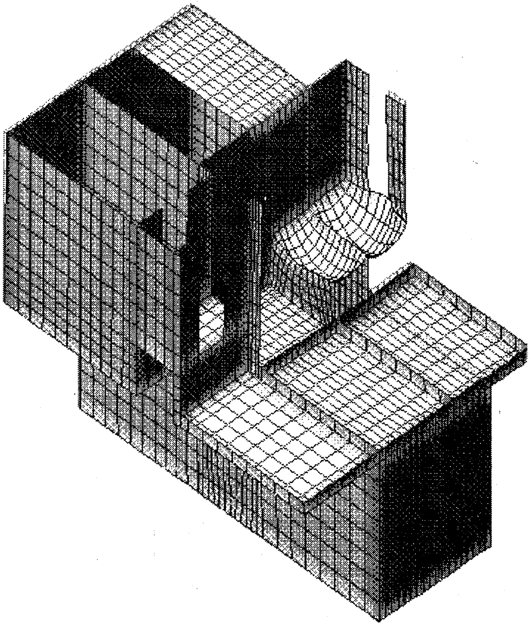
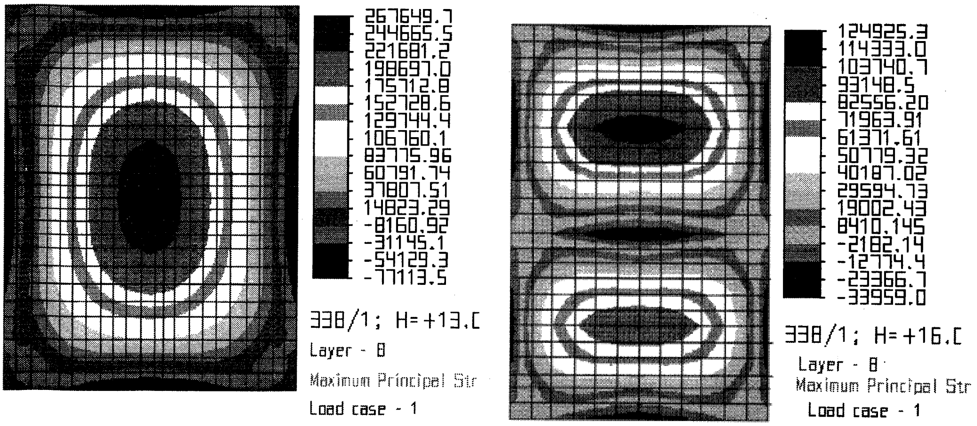


Figure 3. Calculation model of the compartment pool

The stress analysis is carried out under the assumption that the shock absorber distributes the loads evenly across the entire surface of the floor. The pressure then equals 0.1 MPa [6]. Because of the condition that cracks may not form in the floor, it was also assumed that concrete layers extended through the entire floor cross-section. The distribution of maximum stress in layers of reinforced concrete model is presented in Figure 4.



a) b)

Figure 4. The stress distribution in layer 8 (concrete) of the compartment floor, subject to uniform 0.1 MPa pressure: (a) elevation 13.00 m and, (b) elevation 16.00 m

The variation of reinforced concrete characteristics of stress/deformation conditions pass three stages as the external loads increase from zero to those causing structural failure:

- Stage I -- stresses in concrete and reinforcement are small, and are elastic, i.e. linear dependence between stresses and deformations;
- Stage II -- cracks forming in concrete under tension, engaging reinforcement to carry tension loads;
- Stage III -- break-up of cross-section either due to passing the yield limit in the reinforcement or reaching compressive failure of concrete.

Safety factors for the initiation of cracks in the concrete floor were established according to Stage I. Within this stage, elements undergo bending up to crack initiation. With the increase of loads, Stage II begins with the formation of cracks, i.e. cracking the concrete layers in tension. The results show a safety factor equal to 4.1 at elevation +13.00 m and one of 8.7 at elevation +16.00 m. According to this stress analysis, the strength of the compartment floor is sufficient for the type of accident considered during the transportation of the container.

6. CONCLUDING REMARKS

The obtained analytical results are conservative for the following reasons:

- the geometrical sizes of the wall structures are affected in models by the location of the neutral surface of the supports. This means that the sizes of the analytical models increases by half of thickness of wall or floor along each support boundary;
- in the analysis of tensile strength of reinforcement or tensile and compressive strength of concrete, allowable stresses were used instead of yield limits or ultimate strengths;
- for distribution of stresses in concrete across the thickness of the wall, a linear law was used, without consideration of bending diagrams for the deformation of concrete.

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