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Finite element simulation of cracks formation in parabolic flume above fixed service live

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Abstract. In the article, digital simulation data on influence of defect different characteristics on cracks formation in a parabolic flume are presented. The finite element method is based on general hypotheses of the theory of elasticity. The studies showed that the values of absolute movements satisfy the standards of design. The results of the digital simulation of stresses and strains for cracks formation in concrete parabolic flumes after long-term service above the fixed service life are described. Stressed and strained state of reinforced concrete bearing elements under different load combinations is considered. Intensive threshold of danger to form longitudinal cracks in reinforced concrete elements is determined.

1. Introduction

As a subject of inquiry, a parabolic lume made of reinforced concrete was considered. In statement of digital mathematical experiment, the task was set to determine scientifically the degree of reliability of a parabolic flume for long-term service life (more than 50 years) under different types of failures. A solid-state model of stressed and strained state of parabolic flume made of reinforced concrete was built.

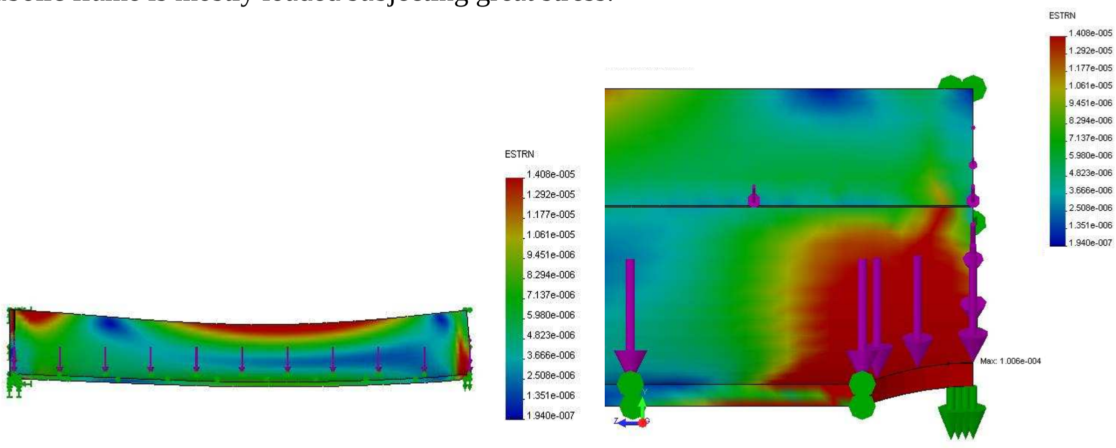
In the present paper, the results of digital simulation of strains and stresses for cracks formation in concrete parabolic flumes after long-term service above the fixed service life are given. Depending on mechanical and mathematical methods used, material and boundary problem statement in the current computation practice, the theory of plastic flow or its special case - strained theory of plasticity - are applied. In general case, to describe plastic behaviour of material, knowledge of three criteria is required: conditions for initiation of flow, flow and law of reinforcement.

2. Materials and methods

The mathematical model was being built on the base of experimental studies confirmed that the flume is necessary to consider as a thin-walled space construction of cylindrical casing type and to compute it with space work taken into account. The whole computation was carried out on the well-known software product Solid Works whose operation is based on the finite element method and that of superelements. Solid Works pacckage developed by Solid Works corporation (USA) is the supplement for automated object-oriented design of solid-state models for machine building products completely using graphic user interface Microsoft Windows. In the Solid Works, drag-drop possibilities are realized, owing to which this package is rather simple in assimilation. Graphic interface Windows makes it possible for designers to improve his/her decisions and to realise them as a virtual prptotype or a solid state model, big assemblies, subassemblies and to carry out a detail drawing and to get the necessary drawing documentation [1].

In the existing designs of the finite element method using three-dimensional isoparametric finite elements node, movements are given, in the global, as a rule, Cartesian coordinate system. Components of deformation tensor are computed with regard to the invariable global basis. The simplest eight-assembly, six-assembly and four-assembly isoparametric finite elements are widely spread [2]. To form rigidity matrix of an ensemble of elements, they require rather small expenditures of computer time and allow one to automate the process of ensembling (construction of finite element grid). The necessary accuracy is achieved at the expence of the grid closeness.

Spreading the existing standard design of the finite element method for the case, when stress and strain state is determined in element local axes coinciding with the main directions of material anisotropy, is of great interest. The number of elements and that of assembly units were 3317 and 6861, correspondingly. Coding of source information was carried out in terms of the increment method taking into account a fragmental representation of parabolic flume as objects of a simple geometric form. The results of computations in the form of a stress intensity diagram on von Mises and absolute movements are presented in figures 2 and 3. It is evident that the support area of parabolic flume is mostly loaded subjecting great stress.



a b

Figure 1. Stress intensity diagram on von Mises; a – side view of parabolic flume; b – detached support area of parabolic flume.

An analysis of the data received showed that the values of absolute movements satisfied the accepted norms of flume designing. The received values of maximum stresses are less than those computed by formulas of normative documents and computation techniques [3, 4] Taking into account that the finite element method is based on general hypotheses of the theory of elasticity, it should be given preference when designing and computing data of structures. Comparisons of movement diagrams by the vertical and the horizontal along and across bearing elements revealed insignificant inner variations. The diagram of total movements (figure 2, a) under crack formation and destruction of the support area is the most interesting. On the diagram, changing of element location due to loads made, as well as noncritical shifts of sides, are shown. These results testify to availability of their great safety margin [5]. Movements by the horizontal along bearing elements show insignificant shifts of support areas for the horizontal reinforced concrete elements.

The diagram of total movements under destruction of only support area of parabolic flume is presented in figure 2, b. At the interface point of horizontal and vertical elements, under structure operation and changes in technical parameters, longitudinal cracks can occur [6]. To avoid this problem, it is necessary to strengthen the detected weak point of the structure because its technical characteristics are at a dangerous threshold of operation. It is also necessary to pay attention to

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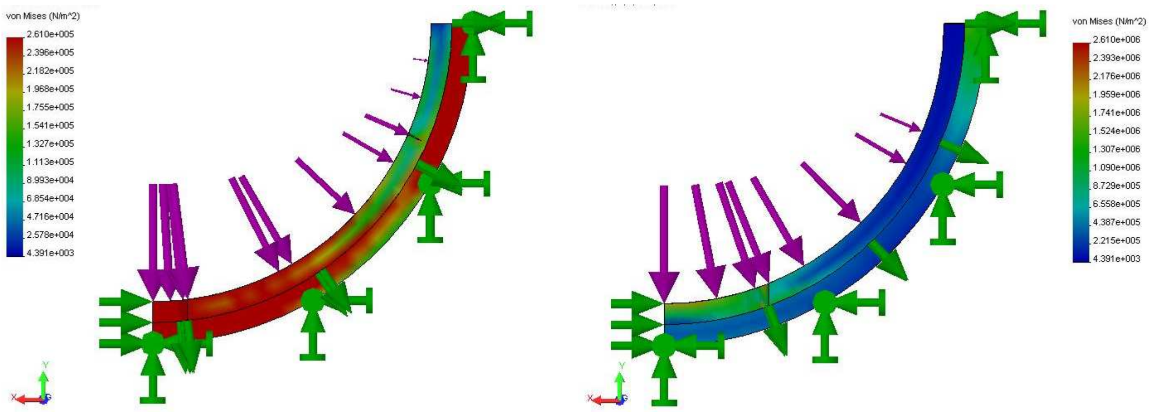
strengthening the reinforcing cage of the parabolic flume. The total diagrams of movements emphasise (figure 2, a) insignificant rigidity of the side horizontal elements that are also in need of reinforcement [7].



a b

Figure 2. Diagrams of total movements on von Mises: a – under crack formation and destruction of support area; b – under destruction of the support area only.

According to the results of comparison for the diagrams of equivalent stress von Mises, the highest stresses occur by the vertical of bearing elements, exactly in the lower part of the structure. This testifies to occurance of critical stresses in the structure base taking both water load and weight of the whole structure. Diagrams of equivalent stress on von Mises by the horizontal along and across the parabolic flume also show the highest stresses arising in the area of the structure support on the base caused by the strains of bearing; elements [8]. Stresses are also in the horizontal reinforced elements.
Carried out simulation of stress and strain state confirmed availability of significant safety of margin in reinforced elements of the parabolic flume. The received diagrams of movements and stresses are within permisible limits of the future operation. A detached fragment of the equivalent stress diagram where formation of a longitudinal crack is shown, is presented in figure 3. Its origin is possible under weakening reinforced cages taking tensible stresses in bending of the parabolic flume. Formation and subsequent opening of cracks above the normative characteristics take place and, this can result in the flume destruction by means of sivde caving. In the course of the digital experiment, the objective to determine breaking stresses, under which this breakdown will happen, was pursued. The parameters of limit equivalent stresses resulting in the structure destruction are received. These values of maximum stresses are less than those computed by formulas [9].

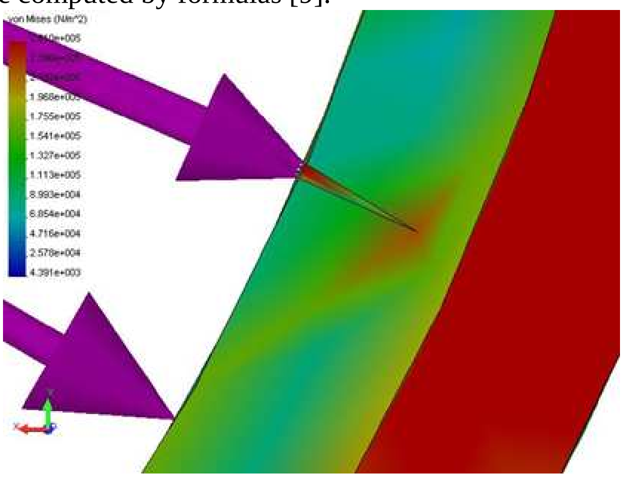


Figure 3. Detached fragment of diagram of equivalent stresses under crack formation.

3. Conclusion

Analysis of the data received shows that the values of absolute movements satisfy the accepted standards of hydraulic structure designing. Taking into account that the finite element method is based on general hypotheses of the theory of elasticity, it should be given preference when designing and computing hydraulic structures. Comparison of the diagrams of equivalent stress von Mises and movements shows that the highest stresses arise across the parabolic flume, exactly at the butt joint of element connections. These results testify to an origin of critical stresses in support areas twice as large as in other areas and under head; increasing this can result in destruction of the considered elements and loss of bearing capacity of the whole structure.

Empirical relations between the change in stress and strain state of the simulated elements and intensity of water level rising are received:

under crack formation and destruction of the support area - $G_{VЭ}$=0,05703a^2+0,0591a-0,227; R^2=0,97;

under destruction of the support area only - $G_{VЭ}$=0,04287a^2+0,0524a-0,0431; R^2=0,98;

As a result of the digital experiments conducted, an intensive danger threshold of stress on the parabolic flume side that can result in the structure destruction was determined.

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