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Mathematical modeling of the influence of defects in structures of an on-farm network of rice systems on their operational reliability

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Abstract. This article presents the results of mathematical modeling of the effects of defects in the structures of an on-farm network of rice systems over a long period of work on their operational reliability. This year marks the ninety years since the first rice system was built in 1929 in the Kuban. In the Krasnodar Territory, rice systems have been used that have been in continuous operation for more than thirty years. Therefore, it is necessary to scientifically substantiate the costs of maintenance and overhaul, and a numerical experiment was carried out on various defects in the structures of the on-farm network of rice systems. Based on field studies, mathematical modeling was performed for the most common defects by the ground-penetrating radar (GPR) sounding—a transverse crack crossing the drainage structure, as well as the destruction of the sides of the well. All calculations were performed on the SCAD Office calculation complex. In the course of mathematical modeling, it was found that the drainage pipeline with a well has a margin of operational reliability, which decreases over the years of use of the structure. In the formulation of mathematical modeling of a model of a drainage structure with a well without defects and damages, the aim was to establish the adequacy of the solid-state model of the stress-strain state at maximum water pressure with existing field tests under various boundary conditions. According to the data of the technical analysis of operational reliability, the operational reliability of the structures of the on-farm network of rice systems is determined and characterized. Provision of the operational reliability of rice systems is to carry out engineering, technical and land reclamation measures for sustainable and effective water conservation, rational use and development of the water management complex as a whole.

1. Introduction

At present, the state of the water basin of the Kuban River is characterized by a high level of economic and integrated development, as well as the magnitude of the irretrievable withdrawal of water resources in Lower Kuban [1]. At the same time, at the present stage of irretrievable withdrawal, the reimbursement of water resources is not provided, especially in the period of low water. There is also non-compliance with sanitary and environmental releases at a sufficient level.

This year marks the ninety years since the first rice system was built in 1929 in the Kuban. Currently, in the Krasnodar Territory there is a rapid revival of the rice industry; for example, in 2015, the area allocated for rice cultivation amounted to more than 170 thousand hectares [2].

Thus, the Kuban River has virtually no free water resources in the lower reaches after the

Krasnodar reservoir, for further development.

All these unresolved problems indicate that it is necessary to substantiate methods for improving the operational reliability of rice systems for their further use in the water sector of southern Russia [3].

In the Krasnodar Territory and the Republic of Adygea, old rice systems are used, therefore it is necessary to scientifically substantiate the costs of maintenance and overhaul, therefore it was necessary to carry out numerical mathematical modeling of the effects of various, most common defects in the construction of rice systems on their further operational reliability.

To do this, it is necessary to carry out the technical justification of the plan for conducting various field studies of long-running structures of rice systems with non-destructive testing devices using the example of the Lower Kuban [4].

Implementation of the operational reliability of the structures of rice systems consists in the implementation of engineering, technical and land reclamation measures for sustainable and effective water conservation, rational use and development of the water management complex as a whole [5].

2. Materials and methods

Field studies of the rice systems were performed using an OKO-2 GPR. The drainage structure in the form of a pipeline was examined in the most detail, since the structure is exposed and accessible for inspection and measurements.

However, the part of the structure that was under water during operation received serious damage, the pipeline was destroyed along the entire length from the junction to the water intake well. The destruction of concrete rings led to the formation of a transverse crack [6].

The destruction of concrete occurred due to the fact that the concrete in this place is in the most adverse conditions and leads to the accumulation of defects and destruction of concrete [7]. When cleaning closed drainage structures from congestion with metal hooks, there is a violation of the butt joints and the inner surface of the pipeline.

Based on field studies, mathematical modeling was performed for the most common defects detected after GPR sounding in the form of a transverse crack crossing the drainage structure, as well as the destruction of the sides of the well. All calculations were performed on the SCAD Office complex [8]; solid-state models of the stress-strain state of the drainage structure were built [9].

In the formulation of mathematical modeling of the model of a drainage structure with a well without defects and damages, the aim was to establish the adequacy of the solid-state model of the stress-strain state at maximum water pressure with existing field tests under various boundary conditions (Figure 1).

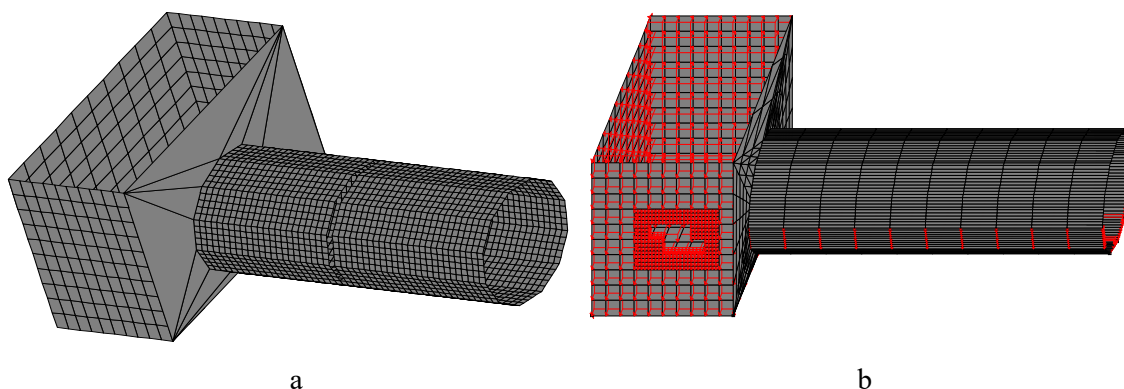| a | b |

Figure 1. Calculation scheme of the solid-state model of the drainage pipeline with a well: a) with a transverse crack; b) with the destruction of the sides of the well.

These methods of mathematical modeling emphasize the adequacy of the model of the stress-strain

state of the drainage pipeline with a well. A three-dimensional analysis of the stiffness of the drainage pipeline with the well, taking into account contact abutment, is performed, the diagram of the total displacements is presented in Figure 2.
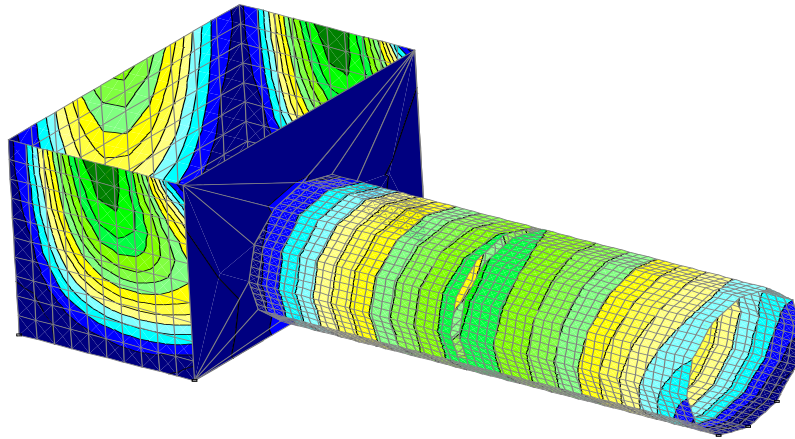

Figure 2. Modeling the effect of a defect in the form of a transverse crack of a drainage structure, an epure of total displacements

In the course of the mathematical modeling of a drainage pipeline with a well with a transverse crack and stability loss when resting on a soil base, it was found that there is a loss of stability of the bearing elements directly in the epicenter of the opening of a drainage pipe crack [10].

Vertical stresses increase along the length of the structure, and horizontal stresses are perpendicular to the structure. Subsequently, with an increase in the length of the crack and its opening, there is a loss of stability, both around the horizontal and vertical axes.

At the junction between the rings, voids were revealed under the ring and to the left of it, but the sealing of the butt joints was broken [11], and water leaked into the soil of the base of the pipeline. When wet soil contacts with concrete, an oxidizing reaction occurs, and therefore caverns and cavities have formed on the surface of the lower part of the structure. In the study of the water-lifting structure, it was recorded that the concrete along the surveyed structure has a porous structure and a different color [12].

It was noted that on the concrete surface there is a deep trace left by the chisel, in comparison with structures that have been in operation for less than 20 years [13]. A large number of cracks were found on the rings at the beginning and at the end, which expose the reinforcement throughout the structure. There are cracks that are directed parallel to the bottom of the wall and also those damaged the side faces of the wall of the well.

The analysis revealed that vertical stresses increase along the axis of the pipeline to the well, and horizontal stresses are perpendicular to the axis of the structure. The calculations of the stress-strain state were performed on the model, considered as a thin-walled shell, taking into account the conditions of its support. The critical stresses of the opening of a transverse crack crossing the drainage structure were determined, the limiting dimensions of its opening were determined, which made it possible to establish that the appearance of a crack is dangerous for the operation of the structure [14].

Intensive hazard threshold is when the crack opening length is greater than 1/3 of the pipeline diameter. A small opening of the crack will cause erosion of the soil base, which is dangerous for the structure (Figure 3).
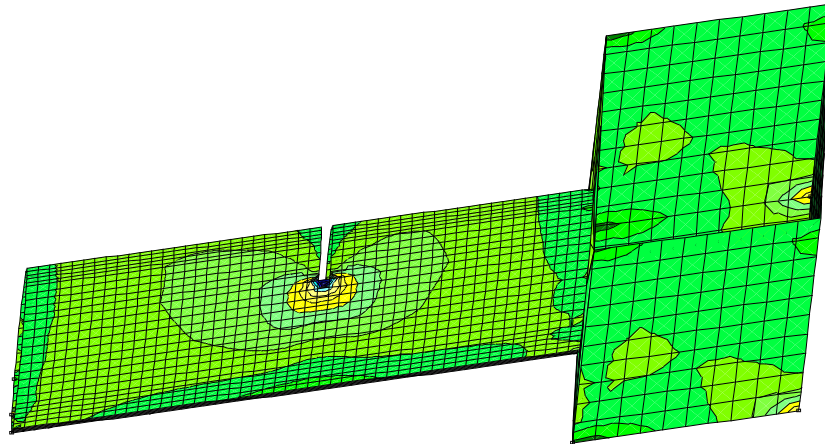
Figure 3. Critical stresses of the transverse crack crossing the drainage structure

Vertical displacements increase vertically down the well, while horizontal displacements are insignificant. The operability of the drainage pipeline with a well is significantly affected by the destruction of concrete and bare reinforcement [15].

The joint of the rings of the 1st and 2nd sections was severely damaged, there were longitudinal cracks with an opening of up to 15-20 mm, indicating the delamination of concrete, which led to exposure of the reinforcement and to the destruction of the concrete body of the structure. There were also cracks in concrete on the vertical faces of the sides of the well. Inclined almost horizontal cracks have completely cut through the section of the rings of the 2nd compartment. The crack opening reached 0.5-1.8 mm, the horizontal displacement of the edges of the cracks was 0.7-1.1 mm, and the upper edge of the well was 22° offset relative to the vertical axis.

In the course of mathematical modeling of the influence of defects on the side of the side of the well of the drainage structure, it was found that there is a loss of stability of the support elements occurring in the middle of the drainage pipe [16], which works like a bending beam. The graphical representation is shown in Figure 4.
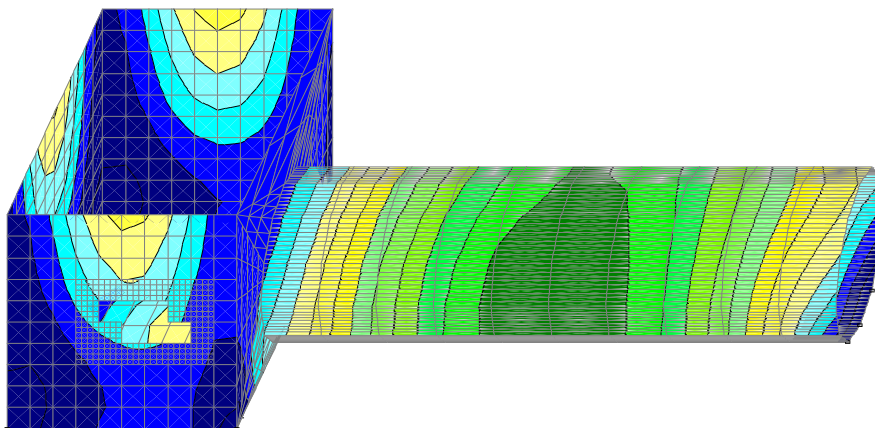

Figure 4. Modeling the effect of a defect in the form of destruction of a side of the drainage structure well, epure of total displacements

In the places of formation of the destruction of defects of the side elements of the well, displacements are insignificant and do not affect the operation of the entire structure.

Concrete of the sides and the bottom of the well are in a state of complete water saturation, the examined areas are torn apart by cracks (crack widths were 0.4, 0.9, 0.2 and 1.2 mm). One of them

was above the south side (5.2 mm). In the 2nd compartment, there were three cracks on the north side (0.2, 0.4 and 0.8-mm wide) and two on the south (1.4 and 1.2 mm wide). There were seven cracks in the 3rd compartment of the structure, the location of which could not be tied to other factors. In the subsequent compartments, one or two cracks were found in the middle part [17].

Figure 5 shows a plot of equivalent maximum horizontal stresses along the drainage pipe with a well, the stresses have the maximum permissible values [18]. When the load increases, the connection of the well with the drain pipe can be dangerous.
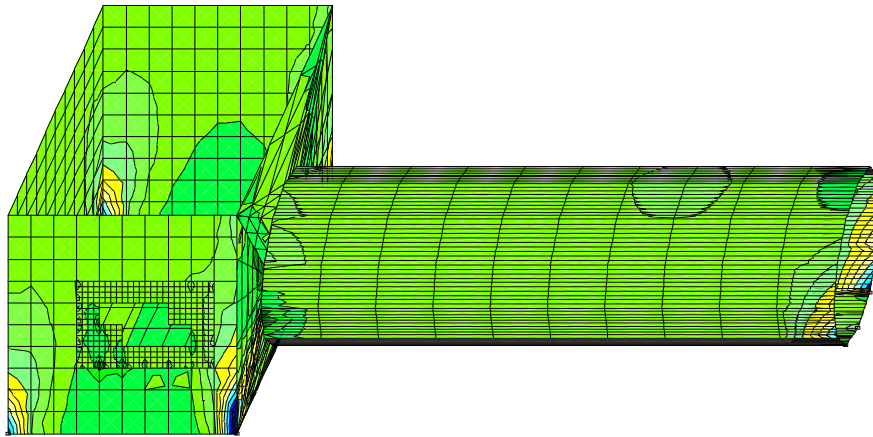

Figure 5. Modeling the effect of a defect in the form of destruction of the side of a drainage structure well, epure of equivalent maximum horizontal stresses along the structure

The maximum equivalent horizontal stresses across the drainage pipe with the well are shown in Figure 6. The stresses, as in Figure 5, have maximum permissible values. When the load increases, the connection of the well with the drainage pipe can be dangerous.
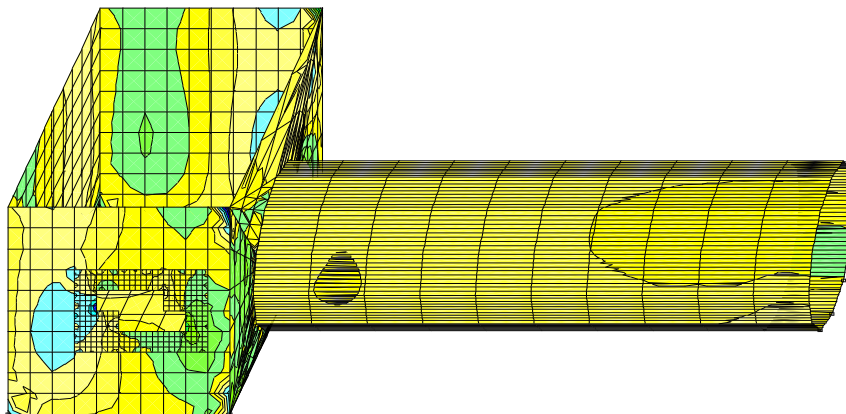

Figure 6. Modeling the effect of a defect in the form of destruction of the side of a drainage structure well, epure of equivalent maximum horizontal stresses across the structure

All cracks completely cut through the section of the structure, so each crack of the western side corresponds to a crack of the eastern side, located opposite the first. This clearly indicates the presence of a crack in the bottom concrete, which connects the opposite cracks in the sides of the well. The thickness of the protective layers is not always satisfied. During the construction of the concrete, B 50 concrete was used.

The calculation of the stress-strain state implied the construction of an adequate calculation model for various operational parameters; zones of formation of defects and damages on the supporting elements of the drainage pipeline with a well, which may contain the same type of defects, were identified. An intensive hazard threshold has been established for the operation of the structure, starting from a diameter of 75 mm of the formation of voids and deconsolidation of reinforced concrete.

The use of mathematical modeling to assess the reserve of capacity of structures of rice systems has shown the ability to improve the quality of control effects of operational reliability.

3. Conclusion

In the course of mathematical modeling, it was found that the drainage pipeline with a well has a margin of operational reliability, which decreases over the years of use of the structure. Mathematical modeling of various faults detected during the GPR sounding and represented by a transverse crack crossing the drainage structure, as well as with the destruction of the sides of the well, was performed. These modeling methods emphasize the adequacy of the model of the stress-strain state of a drainage pipeline with a well.

The results of calculations of the loss of stability and drawdown of the spillway in the form of epures of excess horizontal and vertical equivalent von-Mises and absolute movements were obtained.

A three-dimensional analysis of the stiffness of a drainage pipeline with a well was performed taking into account contact support. The analysis revealed that vertical stresses increase along the axis of the pipeline to the well, and horizontal stresses are perpendicular to the axis of the structure.

According to the data of the technical analysis of operational reliability, the operational reliability of the structures of rice systems was determined and characterized.

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