Finite Element Modelling of the Technical Condition of a Low-Pressure Earthen Dam of Rice Systems Under Increasing Operational Loads

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Abstract. The article deals with the issue of modelling the technical condition of a low-pressure earthen dam of rice systems using numerical calculation methods. The primary task of operating irrigation systems is to rationalize water use by increasing the technological level, improve water management through the use of water-saving technologies and optimal operating modes of the on-farm network of rice systems. Rice is the most productive and water-intensive crop. The most widespread rice cultivation in Russia is in the South, namely in Krasnodar Territory and the Republic of Adygea. The problem of water scarcity in the cultivation of modern rice varieties requires the development of new science-based technological solutions to comply with the regime at the entire stage of cultivation, primarily aimed at saving water resources. Modern approaches and solutions of water regime management at the entire stage of cultivation are relevant with a constant increase in the volume of rice cultivation.

A number of numerical experiments were carried out, which can be divided into two groups. In the first group, numerical calculations of the low-pressure earthen dam of the rice check were performed without the formation of landslide processes, where the goal was to establish the adequacy of solid–state models of the stress-strain condition with existing field tests. The pressure from agricultural machinery passing through a low-pressure earthen dam is taken into account. The second group consisted of numerical calculations of low-pressure earthen dam rice check in the formation of landslide processes in the presence of defects, the result of which was to obtain the maximum allowable sizes of damage. There were performed the simulations and evaluated the impact of the identified damage to the technical condition of the structures of on-farm network of rice systems.

1. Introduction
Currently, Krasnodar Territory and the Republic of Adygea have one of the largest water management complexes in Russia, which was designed and built taking into account territorial hydrological features and currently is operating steadily. The complex includes a modern hydrotechnical system of accumulation and redistribution of water runoff in reservoirs: Krasnodarskoe, Shapsugskoe, Kryukovskoe, Varnavinskoe. A unique network of distribution, discharge, inter-farm and intra-farm channels transports water resources to consumers to rice systems located on the left bank of the Kuban, the right bank of the Kuban and the channels, in the Kuban Delta and the channels [1].

Currently, in Krasnodar Territory, only 60% of the area is in good condition due to soil salinity and a high level of ground water, 19% is in satisfactory condition, and 20.5% is in unsatisfactory
condi tion. As a result, a decrease in the volume of operational and capital planning caused a deterioration in the reclamation state lands under rice [2].

From year to year, the seasonal flow of rivers is significantly distorted by various water management measures. To provide water resources to all users and consumers on the Kuban river (the average annual flow is more than 13 billion dm³, the flow utilization rate is more than 0.86), four reservoirs were built [3, 4]: Krasnodarskoe and three - on its tributaries, the trans-Kuban rivers: Shapsugskoe, Kryukovskoe and Varnavinskoe [5].

Development of approaches and solutions in the field of rational use of water resources of the Kuban river and the potential of the complex and thermal energy resources of the Kuban river climate are used by no more than 50 % and there are objective explanations for this [6]:

1) sharply contrasting disproportion of prices for rice and material and energy resources has led agricultural enterprises to lose profits and, as a result, current capital, without which profitable production is not feasible [7];

2) the lack of water resources for rice cultivation in the amount of up to 1 billion m³, caused by a decrease in reservoir capacity and the lack of a science-based system of rational use of water resources, led to a reduction in lands allocated for the rice cultivation [8].

It is also necessary to note an unfavorable prospective hydrological factor – low water availability. The forecast for a decrease only in the South of Russia is more than 10%. The load on water resources is projected to increase by 8.2%. The problem of lack of water resources on the lands of Krasnodar Territory and the Republic of Adygea continues to be a priority for the agro-industrial complex [9].

A low-pressure earthen dam is a close-shaped model, the width of the ridge of the water support structure ranges from 5.5 m to 6.5 m. On the crest of the structure there are pits and ruts formed as a result of the movement of motor vehicles along the crest of the dam. In the northern part of the dam, there is a 1.5 m subsidence of the ridge and slopes (Figure 1).

![Figure 1](image_url)  
**Figure 1.** Landslide formation on a low-pressure earthen dam of rice systems:a – low-pressure earthen dam; b – landslide formation on a low-pressure earthen dam.

The geometry of the slopes of the low-pressure earthen dam is broken – they are steep and washed away. A significant part of the slopes is overgrown with grass and reeds. Microslides and ground subsidence were formed in the joints between the plates of the upper slope of the low-pressure earthen dam, in the area of the spillway structure location [10, 11, 12].

Planning of a mathematical experiment aims to set the task of modelling the degree of reliability of structures in the on-farm network of rice systems. The main damages and defects that occur during long-term operation of structures of the on-farm network of rice systems and agricultural machinery passing through a low-pressure earthen dam are considered.

At the beginning of planning a mathematical experiment, a solid–state model of the stress-strain state of a water supply pipeline with a well without defects and damages was constructed based on experimental studies. All calculations were performed on well-known software products: SCAD
Office and SolidWorks, and assumptions were made for the numerical calculation method [13, 14].

2. Materials and methods
The calculation of simulation modelling of the stability of low-pressure earthen dam of the rice check, paved dry way with compaction length 720.2 m, with a maximum height of 1.5 m, width of the crest 8 m, the absolute mark of top 3.5 m, with the formation of the top of the slope mV=3.2 mm, made using known software packages: SCAD Office and SolidWorks.

In the course of the work performed to prepare the initial data and materials, the following data were obtained:
1. Design, topographic, geodetic and cartographic data were collected and processed;
2. Topographic survey of low-pressure earthen dam structures was carried out;
3. Verification measurements of zones, sections, structures where adverse processes, defects and damages of structures and equipment take place were carried out;
4. Photo and video recording of defects and damages of structures and equipment that reduce their safety were made [15];
5. Graphic results of the topographical survey were designed;
6. Assessment of compliance of operating conditions with safety requirements was carried out;
7. Probabilities of failure of technical devices with the consequences of a certain level (class) for a certain period of operation of a dangerous production facility (technical risk) were identified.

Violations were detected during the survey.
1. Geometry of slopes (steep, washed away) of low-pressure earthen dam was destroyed. There is a ridge subsidence in amount exceeding the maximum permissible value of 0.05 m;
2. There are chips, cracks, corrosion of reinforcement and destruction of concrete at the entrance of a low-pressure earthen dam [16];
3. There was the deterioration of concrete and exposure of reinforcement on the cap of the outlet work of the low-pressure earthen dam.

One of the problems of operating an on-farm network of rice irrigation systems is irrigation erosion, which causes the siltation and contamination of structures. A significant part of the damage caused by irrigation erosion is a result of consequences of erosion of the on-farm network of rice irrigation systems [17].

When entering the parameters of the low-pressure earthen dam of the rice check, we used the results of field studies on 12 wells in 4 design lines performed by the Department of Geology and Hydrogeology of Kubanvodproekt, as well as various topographic and geodetic data that allowed us to clarify the boundaries of engineering and geological elements of soils and determine the dynamic properties of the structure and the soil base [18, 19].

At the first stage, the modelling of landslide formation on the slope of the low-pressure earthen dam of the rice check was performed. Figure 2 shows the fragments of the von Mises movement diagram. The stages of the mechanism of dynamics of landslide development on the upper slope of the low-pressure earthen dam of the rice check are highlighted, namely, the first stage of landslide preparation [20]; the second stage of formation; the third stage of stabilization of landslide processes.
Figure 2. von Mises movement diagrams: a – stage of preparation of the landslide; b – stage of formation; c – stage of stabilization.

Figure 3 shows fragments of the diagram of von Mises equivalent maximum stresses, and also reveals the stages of the mechanism of dynamics of landslide development on the upper slope of the low-pressure earthen dam of the rice check, namely, the first stage of landslide preparation, the second stage of formation, and the third stage of stabilization of landslide processes [21].

Figure 3. Diagrams of von Mises equivalent maximum stresses: a – stage of landslide preparation; b – stage of formation; c – stage of stabilization.

At the second stage, the modelling of impact of moving heavy agricultural machinery along the embankment of the low-pressure earthen dam of the rice check was simulated. Figure 4 shows a diagram of the total movements of von Mises [22] without the formation of landslide processes on the upper slope of the embankment of the low-pressure earthen dam of the rice check [23].

Figure 4. Diagram of total movements of von Mises, without formation of landslide processes.
Figure 5 shows a diagram of von Mises movements, without formation of landslide processes.

![Diagram of von Mises movements](image)

**Figure 5.** The diagram of von Mises movements without formation of landslide processes.

The main property of the landslide process mechanism on the upper slope of the low-pressure earthen dam of the rice check is its certainty in terms of displacement, i.e., relative to the movement of one part of the landslide over another, along surfaces and zones of weakening. In some cases, there is a shift in the structure of the construction or its individual elements, in others, the movement occurs in the form of a flow [24, 25]. Based on the results of calculations, it was found that the stability coefficient in the upper slope of the low-pressure earthen dam of the rice check:
- in the shot calculated I-I $k_y=2.35$;
- in the shot calculated II-II $k_y=1.81$;
- in the shot calculated III-III $k_y=3.52$;

Figure 6 shows a diagram of equivalent maximum von Mises stresses without formation of landslide processes.

![Diagram of equivalent maximum von Mises stresses](image)

**Figure 6.** Diagram of von Mises equivalent maximum stresses without formation of landslide processes.

The results of calculations in the form of stress and displacement diagrams at mathematical modelling of the formation of landslide processes on the slope of a low-pressure earthen dam from the impact of agricultural machinery are presented in Figure 7.
As a result of numerical experiments, solid-state models of the stress-strain state of the low-pressure earthen dam of the rice check were performed without formation of landslide processes, where the goal was to establish the adequacy of solid-state models of the stress-strain state. The second group consisted of numerical calculations of the water supply pipeline with a well and the low-pressure earthen dam of the rice check during the formation of landslide processes in the presence of identified defects, as a result of which the maximum permissible damage sizes were obtained, which allow the low-pressure earthen dam to support a structural load during the long-term operation.

The simulation results show that the stability coefficient in the upper slope of the low-pressure earthen dam of the rice check corresponds to the regulatory documents.

3. Conclusion
Defects in structures of the on-farm network of rice systems, left without observation, lead to a negative transformation of structural load-bearing elements, which reduces their load-bearing capacity, up to the complete termination of functioning of both the entire structure and individual elements. It determines the relevance of finding and implementing effective approaches to assessing the actual state of the construction of the on-farm network of rice systems and forecasting the remaining reserve, ensuring the optimal operational, tactical and strategic planning of measures to improve the reliability, safety and durability of structures of the on-farm network of rice systems. A number of numerical experiments were carried out, which can be divided into two groups. In the first group, numerical calculations of the low-pressure earthen dam of the rice check were performed without formation of landslide processes, where the goal was to establish the adequacy of solid-state models of the stress-strain state. The second group consisted of numerical calculations of the water supply pipeline with a well and the low-pressure earthen dam of the rice check during the formation of landslide processes in the presence of identified defects, as a result of which the maximum permissible damage sizes were obtained, which allow the low-pressure earthen dam to support a structural load during the long-term operation.

As a result of the conducted numerical experiments, construction zones that may contain the same types of detected defects and damages and which makes it possible to streamline the process of laying GPR profiles and determining the points at which measurements that should be made during field surveys of structural elements of constructions were identified.

The simulation results show that the stability coefficient in the upper slope of the low-pressure earthen dam of the rice check corresponds to the regulatory documents.

4. References
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Figure 7. Diagrams at the formation of landslide processes: a – diagram of von Mises displacements; b – diagram of equivalent maximum von Mises stresses.
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