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Directions of improvement of massive hydraulic retaining structures

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Abstract. The article deals with the issues of improving hydraulic retaining structures of the gravity (massive) type. In order to reduce the cost of building gravity (massive) dams and increase their efficiency, a constant search for new, more efficient design solutions is underway. The purpose of the research is to analyze the main directions of improving hydraulic retaining structures of gravity type. The article suggests a more effective method for improving concrete gravity dams, based on the idealization of structural and technological solutions. Its peculiarity is that on the basis of the identified solutions of the traditional method, an effective design of a concrete dam and the technology of its construction are selected, and then promising, patentable solutions are developed, which in their properties approach the ideal structures. In accordance with the method, the structural and technological solutions of the gravity dam with the use of coarse-pored concrete were developed. The design is high-tech and allows cooling of the dam mass by filtering water through large pores of concrete.
Keywords: Hydraulic engineering, concrete gravity dam, dam design, manufacturability, rolled concrete, dam design improvement.

1 Introduction

Ensuring the reliable operation of hydraulic retaining structures for the present time is a very relevant requirement for both design enterprises and organizations operating these facilities [1, 2]. At the same time, an important condition for the implementation of design solutions for these critical structures is the choice of the most rational design that provides high efficiency and adaptability [3, 4]. It is especially important to meet these conditions for retaining structures of the gravity (massive) type, since they are very material-intensive and require significant financial resources for construction, as well as a long time for their construction [5, 6]. In order to reduce the cost of building such dams, scientists, designers and builders are constantly working to create more advanced design and technological solutions [7-9].

2 Materials and Methods

The traditional scientific method of expert assessments is known for finding ways to improve gravity dams. The essence of the method is that all known solutions are analyzed,

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and the most effective ones that have been tested are recommended for implementation [10, 11]. An important advantage of the traditional method is that already implemented solutions are considered. Its disadvantage is that these solutions, for the most part, provide a local effect and do not target developers to find a general direction that guarantees maximum effect.

For the first time, the traditional method successfully revealed an effective direction for improving gravity dams with a focus on their construction using road technology. This technology and the design of the dam were proposed by American hydraulic engineers. The dam for progressive road technology was structurally a triangular profile, the central array of which was formed from rolled concrete, and on the periphery was covered with protective screens of dense vibrating concrete. From the pressure side, the screen was made waterproof, and from the bottom – frost-resistant [12, 13].

The dam of this design was built by road technology in layers for its entire length. The concrete mix was delivered to the structure by dump trucks, and directly to the place of laying – by bremsbergs (without the use of traditional concrete-laying cranes). The mixture was distributed over the surface with scrapers, leveled into a layer with bulldozers, and compacted with rollers. Road technology made it possible to build dams with such a high intensity that it was completely impossible for crane laying.

Scientists of the Samara State University of Architecture and Civil Engineering have proposed a more effective method for improving concrete gravity dams, based on the idealization of structural and technological solutions. It is characterized by the fact that on the basis of the identified solutions of the traditional method, an idea of the effective design of a concrete dam and the technology of its construction is formed, and then promising, patentable solutions are developed, which are close to ideal in their properties.

The improvement of the structures of concrete gravity dams by the idealization method is carried out in two stages. At the first stage, the traditional method is used, effective solutions known in the world practice are identified, they are taken as a standard for further search for a more perfect (ideal) solution. At the second stage, an idealized solution is developed using special techniques used in inventive activity. The effectiveness of an idealized solution is evaluated by the positive impact it has on changing the final result – reducing the cost of building a dam. The advantages and disadvantages of the developed solution are judged by the effect of the idealized solution.

3 Results

The analysis of traditional methods of improving gravity dams has shown that despite the obvious progressiveness of the method of applying road construction technology, the design of such a dam does not have high technological efficiency. This is indicated by the following two reasons.

The first reason. When the dam body is built in layers, each layer is obtained as a three-element layer. The layer must be formed by three types of concrete of different compositions, three technological flows with the use of three types of technical means. The technologies of work on these elements are not balanced in time in terms of intensity, productivity (capacity), which causes an increase in the cost of construction. The experience of the construction of the Upper Stillwater dam (USA) has shown that the labor costs for the formation of a monolithic shell are comparable to those for rolled concrete. At the same time, in many cases, monolithic shells do not perform their main functions: in the pressure zone, the dam screen loses its waterproofness property when the solidity is violated. This is one of the main reasons that prompted specialists to improve the design and technological solutions of protective shells in the first place.

So for the pressure zone, instead of a concrete screen, several options for the device of waterproof screens made of other materials were additionally considered. The 3 mm thick stainless steel sheet screen was rejected due to the high cost. Bituminous screen in the wall of precast concrete blocks-rejected due to the need for a large number of operations (multi-work). The screen of the cementation curtain device is proposed for use without the required justification. To protect the rolled concrete in the bottom face of the dam, the builders had to create concrete screens up to 6 m thick (Bureyskaya HPP, Russia), which led to a reduction in the volume of rolled concrete up to 50% [14], but also to a significant increase in the cost of construction of the structure. An option was also considered, in which instead of a concrete screen, it was proposed to use a trough-shaped precast concrete element with foam filling the cavity. The option was considered impractical, since it was necessary to use a mounting crane. Another more advanced option was also considered, which provides for the use of a reinforced concrete slab with a tiled foam insulation on the side of the solid concrete. The plate was proposed to be formed by shotcrete, so as not to use mounting cranes. The method was recommended to be used in the construction of the dam by steps, and the plate was formed from the bottom edge. It should be noted that the considered methods did not solve the problem of ensuring the stability of the dam to overturn when operating in harsh Russian conditions.

The second most important reason for the lack of technological efficiency of a dam made of rolled concrete is that the solidity of its array is not ensured, horizontal construction seams open, the pressure screen becomes water-permeable, which is completely unacceptable [15].

Hydraulic engineers of Western countries have implemented two options for localization of filtration in structures without the device of shells in order to ensure the possibility of layer-by-layer construction of the structure with one technological flow and an unchanged set of technical means. Thus, during the construction of the Upper Stillwater dam, the shells performed only the functions of the formwork, and waterproofness was provided to the entire array by adding an additional 170 kg/m3 (70%) of fly ash to the cement (77 kg/m3). In the forecasts, it was noted that this method of ensuring the waterproofness of dams has become a defining trend in the practice of world dam construction in recent years, despite the need to increase the consumption of binder (cement plus fly ash) in the range of 150-225 kg/m3 [16].

During the construction of the Willow Creek Dam (Oregon), protective elements were also abandoned in favor of improving the technological design. When using a binder in the volume of 67 kg/m3 through the array of the structure, intensive water filtration was observed, due to the reduced density of concrete and violation of the monolithic structure. The decrease in water permeability of the object was provided by cementation of the entire structure after its construction. But this solution applied to the beginning of filling the reservoir cannot be evaluated unambiguously positively, since it is possible that tensile stresses may appear in the central zone of the dam after filling the reservoir.

The experience of building two dams showed that the solutions used provided the required water resistance, but did not ensure the solidity of the dam body (Fig 1)). The opening of the seams in the lower zone of the structure could significantly reduce the stability of the dam to overturn, as well as lead to freezing of the concrete of the central zone from the lower side of the dam [17].

Based on the analysis of the shortcomings of the traditional method of improving concrete gravity dams, the university staff proposed a more effective method. It is based on the idealization of structural and technological solutions. The developed method involved two stages. At the first stage, the initial reference design was determined on the basis of traditional solutions, and at the second stage, the search for an idealized solution was carried out.

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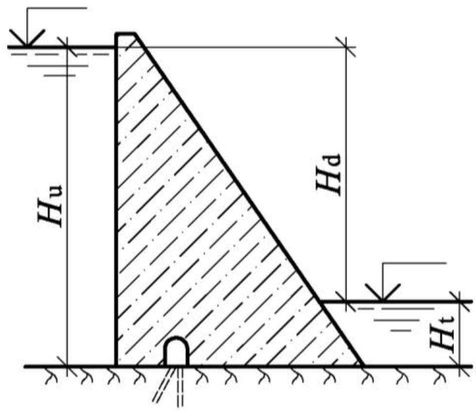

Fig. 1. Massive dam body.

The idealized method reveals the characteristic ideal properties of both the construction of a gravity dam made of rolled concrete and the road technology of its construction, as well as the effectiveness of their application in comparison with the traditional method. The ideal design of the gravity dam reflects the profile of the ground dam, the array of which is made of low-cement rolled concrete, and on the periphery is covered with protective elements of the film type from the negative effects of pressure water, negative outdoor temperatures and atmospheric moisture. When the structure is idealized, zoning of the structure with vertical construction seams is excluded. At the same time, it is allowed to create horizontal zones by the device of horizontal construction seams.

The dam of the ideal design is planned to be built according to the ideal road technology, taking into account the experience of American hydraulic engineers. The difference lies in the fact that the technological process of dam construction operates with high intensity only for one summer period, and the masonry mass is cooled conditionally instantly to a stable operating temperature by the beginning of the winter period.

Two important advantages are inherent in the ideal design of the dam and the ideal technology of its construction. First. It can be built in a single process flow with high intensity and a constant set of high-performance technical means without the use of concrete-laying cranes and formwork, and, most importantly, with the use of one type of concrete mixture in the layer. It was assumed that the time and resources spent on the creation of protective film elements are very small and do not have a negative impact on the functioning of the main technological process. Second. Idealization indicates the main direction of improvement of gravity dams, although the developed solutions do not have such properties in many cases,but only approach them.

An idealized approach was applied to the development of a more advanced gravity dam design. At the same time, at the first stage, based on the analysis of traditional solutions for gravity dams made of low-cement rolled concrete, mutually dependent disadvantages are identified. The first of them is the non – technological design of the dam. The disadvantage is due to the need to use a large number of operations (multi-work), as well as the presence of openings of horizontal construction seams, which makes the pressure screen water-permeable. The second is the use of an imperfect method of cooling the concrete mass, as a consequence of the imperfect design of the dam.

According to the principle of idealization, both solutions must be radically effective, compatible for operation, capable of providing conditionally instantaneous cooling of the concrete mass to a stable temperature of the operating period at high rates of dam construction.

The goal of idealizing the design was achieved by hydraulic engineers of the Samara State University of Civil Engineering in cooperation with designers and builders. In the construction of the dam, it is proposed to use coarse-pored concrete instead of traditionally rolled concrete in accordance with the developments [14]. The resulting idealized design of the dam provided high technological efficiency, and it was proposed to use an idealized original method for cooling the array. The essence of this method is as follows: the concrete of the summer masonry before the onset of the winter period is cooled with water filtered by the manifestation of gravity forces through large pores of the concrete of the dam array. Cooling is carried out in layers in queues or on the entire height of the array of summer masonry (Fig. 2).

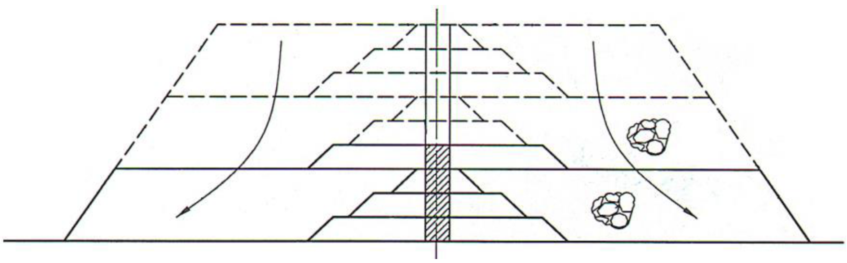

Fig. 2. Laying of concrete layers in the dam.

4 Discussion

The proposed idealized method of building a gravity dam is compatible with the road technology of dam construction. It provides for the conduct of work in layers for the entire length of the dam. The concrete mix is delivered to the structure by dump trucks without the use of concrete-laying cranes. The mixture is distributed over the surface by scrapers and leveled by bulldozers, and compacted by rollers. However, this uses coarse-pored concrete, in the array of which, after compaction, pores remain.

When constructing a gallery in the body of the dam, the following solution is proposed. Each layer within the cavity is formed from two materials: the main part-layers of coarse-pored concrete mix, and the layer within the design profile of the gallery - from medium-grained sand. First, a layer of concrete mix is formed with a free slope towards the gallery, and then a bulk shaper is used. After creating a cavity and gaining strength with concrete, the mold is removed by pneumatic transport to the cavalier for repeated use. Traditional cement loaders are used for sand mining and loading into the pneumatic transport tank. From the cavalier, the sand is fed and placed in the gallery layers by the same technical means as for the concrete mix.

The advantage of the proposed method is not only that it is compatible with the layer-by-layer construction of the dam. It is more technologically advanced, since the combined chain of labor – intensive processes (installation – dismantling of formers-production of precast concrete elements) is excluded from the technology, which reduces the labor intensity of work and the cost of manufacturing reinforced concrete structures.

When developing the technology for the construction of a gravity dam made of coarse-pored concrete, it was important to confirm the possibility of levelling and compacting the concrete mixture with traditional high-performance bulldozers and pneumatic rollers used for traditional rolled concrete. Confirmation was achieved at the experimental construction site of the Shulba hydroelectric complex (Russia). It was proved that the portions of the concrete mix with a volume of 3 and 6 m3 were successfully leveled by a bulldozer with a traction force of 25 t in layers of 0.30-0.75 m, and compacted by three-axle dump trucks with a lifting capacity of 27 t for 4-5 penetrations. The conclusion is made about the possibility of compaction of a large-porous mixture by meter layers when using traditional pneumatic rollers and vibratory rollers. It is established that the concrete layer compacted by pneumatic rollers must be additionally rolled with a light smooth roller in one pass.

5 Conclusions

1. The analysis of methods for improving gravity dams made of low-cement rolled concrete by idealizing structural and technological solutions in combination with the consideration of traditional construction methods ensures maximum efficiency of the final result by targeting specialists to develop solutions with properties close to ideal.
2. By the method of idealization of technical solutions, an idealized design of a gravity dam made of coarse-pored concrete, as well as a method of cooling it, has been developed, which will ensure the solidity of the dam array during its layer-by-layer construction at an extremely high rate of growth of the structure in height (mainly during one summer period). The developed solutions will provide a significant reduction in the cost of constructing the dam.

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