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Water impermeability of hydraulic concrete based with thermal power plant waste substrate

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Abstract. One of the main factors in ensuring the reliability of concrete used in the construction of hydraulic and reclamation facilities is their waterproofing and frost resistance, and the design of the optimal composition of concrete to ensure waterproofing is of great importance. The main goal of the study was to select the water/cement ratio of the concrete mix not only in terms of concrete strength but also in terms of concrete strength, to ensure the optimal concentration of aggregates for dense structural concrete and finally to increase the water permeability of hydraulic concrete using microfillers and chemical additives. In the study, industrial ash (Angren Thermal Power Plant) was used to modify technical lignosulfonates and prepared a plasticizer L-2 chemical additive. Studies have shown that if the size of pores and capillaries that occur in the concrete structure is less than 10-5 cm, they will not allow free water to pass through. But if these dimensions are larger than 10-5 cm, they will have the property of water permeability. The size of the pores formed in the cement gel, which is usually used in the preparation of concrete, is less than 10-5 cm, and they are impermeable to water. However, the sizes of capillaries and pores of different sizes formed in the concrete structure may vary depending on the factors listed above (10-6 - 0.2 cm). Based on the research, the technological factors affecting the waterproofing of hydraulic concrete were analyzed. It was argued that the use of L-2 plasticizer chemical additive in the amount of 0.25% of the cement mass in the preparation of hydraulic concrete can reduce the water-cement ratio by 18% and increase the waterproofing of hydraulic concrete by 3 times. In addition, it was considered that by waterproofing open pores and capillaries in freshly poured concrete, their waterproofing can be increased by 20 .... 30 times.

1. Introduction

In present more than 20 million hectares of land, including 3.2 million hectares of irrigated land is used in agriculture for crops, producing food products for population and necessary raw materials for the industry.

Water is a necessary part of all technological processes in agriculture and industry in all regions of the earth. Therefore, the efficient use of land and water resources in agriculture depends largely on the technical condition of hydraulic and reclamation facilities and their rational use [1, 2, 3, 4, 5].

Concrete used in the construction of hydraulic structures is chronically or intermittently exposed to water, unlike ordinary heavy concrete. One of the main factors in ensuring the reliability of concrete used in the construction of hydraulic and reclamation facilities is their waterproofing and frost resistance [6, 7, 8]. In ensuring the waterproofing of concrete, first of all, the design of their optimal composition is of great importance.

Several scientific studies have been conducted on the design of such concretes, the main measures are as follows, the use of fillers that can ensure the waterproofing and frost resistance of concrete, the choice of water/cement ratio of concrete mix determination of the optimal amount of consumption; ensuring the optimal concentration of aggregates for the preparation of dense structural concrete and finally increasing the waterproofing of hydraulic concrete with the rational use of microfillers and chemical additives in the technology of preparation of concrete was accepted as the main goal of the study [9, 10, 11, 12].

The government is carrying out wide irrigation and reclamation measures to increase the efficiency of irrigated lands and their reclamation conditions. However, due to global climate change in recent years the reclamation conditions of irrigated lands are degrading as the result of periodic water deficit and deterioration of the significant portion internal irrigation system [13, 14, 15].

The main goal of the study was to select the water/cement ratio of the concrete mix not only in terms of concrete strength but also in terms of concrete strength, to ensure the optimal concentration of aggregates for dense structural concrete and finally to increase the water permeability of hydraulic concrete using microfillers and chemical additives. In the study, industrial ash (Angren Thermal Power Plant) was used to modify technical lignosulfonates and prepared a plasticizer L-2 chemical additive [16, 17, 18].

2. Methods
Physical-mechanical, technological and operational properties of hydraulic concrete used in the construction of hydraulic structures are tested based on current regulatory codes in State Standard of Uzbekistan (O'zDSt) 26633-85, and state standards and obtained results were analyzed by "Statistical processing methods of test results" (O'z RST 20522-96).

Angren Thermal Power Plant and industrial ash were used for modification of lignosulphonate and plasticizing agent L-2 was prepared for research. Current State Standard of Uzbekistan (O'zDSt) 24211-80 and recommendations for the use of chemical additives were complied with to prepare L-2 plasticizing chemical agent.

To conduct the experiments hydraulic concrete composition was designed based on the current "absolute volume method" and concrete components were considered to be in "absolutely dry state".

To check the operational condition of hydraulic concrete, natural moisture contents of concrete components were determined and the experiments were carried out by using necessary correction factors for the composition determined in laboratory conditions.

3. Results and discussion
As opposed to ordinary heavy concrete, concrete used in the construction of hydraulic structures is under the influence of water constantly or periodically.

Concrete used in the construction of hydraulic engineering structure differs from regular concrete by that it is under the influence of water occasionally or permanently. The reliability and safety of hydraulic structures depend on a number of factors. The most important of those factors is physical-mechanical and other properties of the concrete used in them. Hydraulic and other types of concrete are multi-component artificial stone material. Therefore, each component of concrete can affect more or less on physical-mechanical and other properties of hydraulic concrete [19, 20, 21, 22].

Concrete water impermeability and frost resistance are of the main factors in providing the reliability of concrete used in hydraulic and reclamation structures. Firstly, designing the optimal water content of concrete is very important in providing concrete water impermeability. The number of studies has been carried out in the field of designing such concrete composition and the main goal of such studies is to provide hydraulic concrete water impermeability by using necessary additives providing concrete water impermeability and frost resistance, taking water-cement ratio not just by concrete strength but also by its durability, determining optimal use of cement amount, providing an optimal concentration of concrete aggregates for dense concrete, using micro-aggregates and chemical additives efficiently.

Hydraulic concrete as well as the other types of concrete is a capillary porous artificial stone material with various characteristics. That means that the sizes of capillaries and pores can have various sizes related to the factors listed out above [23]. The research carried out has shown that if the sizes of capillaries and pores forming in concrete don't exceed 10^{-5} centimeters, free water doesn't move through it. But if these sizes exceed 10^{-5} centimeters, then concrete becomes water-permeable [18]. Usually the pore sizes forming in cement gel used in concrete preparation don't exceed 10^{-5} centimeters and they don't let water move through them. However, the sizes of capillaries and pores forming in concrete can be of various sizes $(10^{-2}\dots 0.2 \text{ cm})$ depending on different factors.

Just life for any other type of heavy concrete water permeability of hydraulic concrete depends on the sizes of pores and capillaries in it and their positional relationship. This is the reason why it is very important to determine the volume of macro-pores in concrete in advance:

$$V_{mg} = \frac{100 \cdot (C_w - 2 \cdot W \cdot C_c)}{1000} \tag{1}$$

where:
C_w *is* the amount of water needed for the preparation of 1 м^3 volume of concrete mixture, kg/m^3;
C_c is the amount of cement needed for the preparation of 1 м^3 volume of concrete mixture, kg/m^3;
W is the ratio of bound water with respect to the mass of cement, %.

The research showed that chemically bound water amount in concrete is 12…16% depending on cement type and concrete hardening time. Based on this and by equation (1), it was observed that the number of macro-pores in concrete may have a wide range of values.

It has been determined experimentally that for hydraulic concrete this value may range between 5 to 42%. It has also been determined from the results of the experiments, that mostly following factors may noticeably affect the macro-pores in hydraulic concrete: water-cement (W-C_w) ratio in the concrete mixture, cement hydration degree, use of chemical additives and concrete mix compaction degree. It was determined that a decrease of (W-C_w) ratio, an increase of cement hydration degree, and efficient use of chemical additives may result in a decrease of macro-pores in concrete.

That in turn allowed for the decrease of concrete water permeability. Determining water permeability of concrete is a relatively difficult process and it can be determined in laboratory conditions or during the operation of buildings and structures.

Testing concrete water permeability in the laboratory is an important task because the most optimal concrete mix can be designed using various technological measures and based on control of concrete water permeability to a certain degree. Nowadays, the evaluation of concrete water permeability in terms of filtration coefficient K_f is one of the most optimal methods.

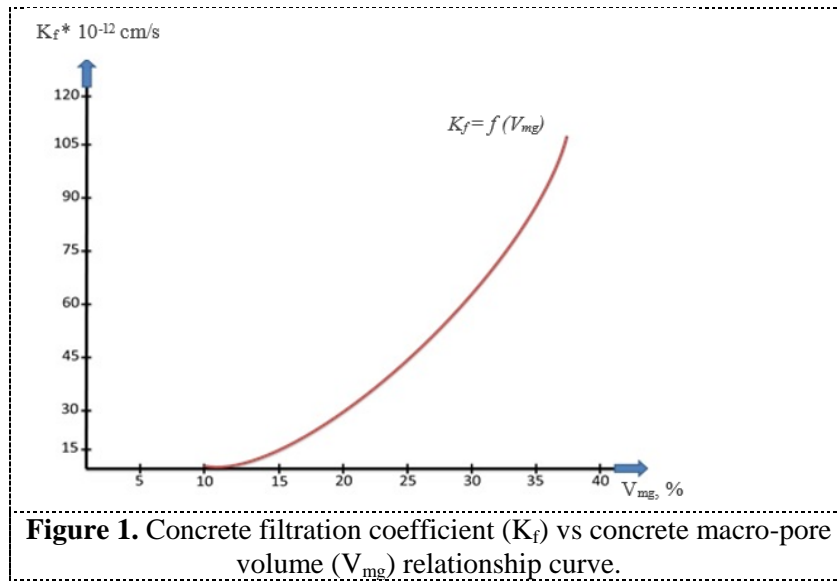$$K_f = \frac{Q}{A \cdot t \cdot (P_1 - P_2)} \tag{2}$$

where:
Q is the amount of water passing through the concrete sample;
A is the filtration cross-section area;
$P_1 - P_2$ is pressure gradient;
t is filtration time.

Figure 1. Concrete filtration coefficient (K_f) vs concrete macro-pore volume (V_{mg}) relationship curve.

Mainly two categories of concrete samples were prepared to study hydraulic concrete permeability. Concrete strength and flowability were taken as constant.

The first category of concrete samples was prepared without any chemical additives, and the second category was prepared by adding modified lignosuphonate L-2 to cement mass in the amount of 0.25%. The concrete samples were tested in 28 days and their permeability was determined. Figure 2 shows the relationship curve of concrete water permeability vs. the macro-pores in them.

Hydraulic concrete water permeability depends on the composition and age of concrete. If we study hydraulic concrete by dividing them into two categories conditionally, they will be of dense structure (Fig. 2a) and granular structure (Fig. 2b).

Figure 2. Hydraulic concrete composition; a) – dense structure; b) – granular structure; 1 – cement mixture; 2 – large aggregate
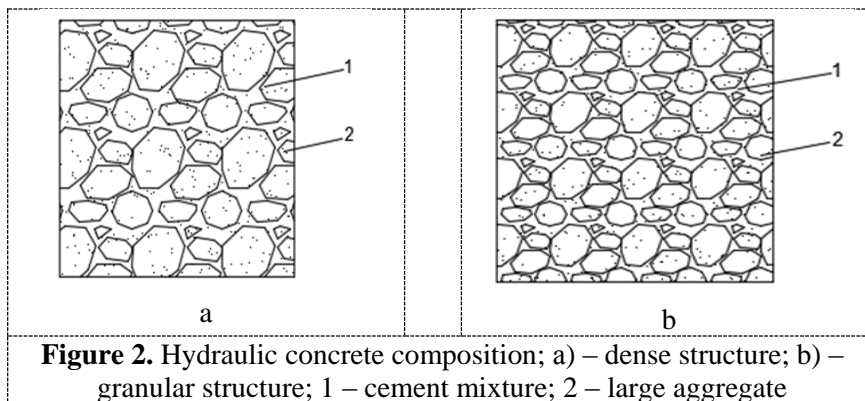
The Macro-pore amount in dense concrete is much lower than the number of micro-pores and concrete water permeability mainly depends on cement stone properties. In granular composition concrete the large aggregate amount is relatively higher and they are densely positioned, thus the process of filling their voids with normally viscous cement mixture is difficult, which results in the formation of macro-pores between large and small aggregates of concrete.

That in turn will lead to the increase of concrete water permeability. When dense concrete water permeability is determined using the above given 2nd equation, it seems like they are totally water impervious, because water won't flow through micro-pores in cement stone if there are no mechanic or contraction cracks in hydraulic concrete. In such cases hydraulic concrete water permeability directly depends on the pressure gradient. Thus, the 2nd equation can be used only for cases when the

pressure gradient is $(P_1-P_2)<2$ kg/sm^2. For cases when the pressure gradient is ≥ 2 kg/sm^2, according to the State Standard of Uzbekistan (O'zDSt) 26633-85, it is very important to choose hydraulic concrete by their water impermeability class in providing hydraulic structure safety.
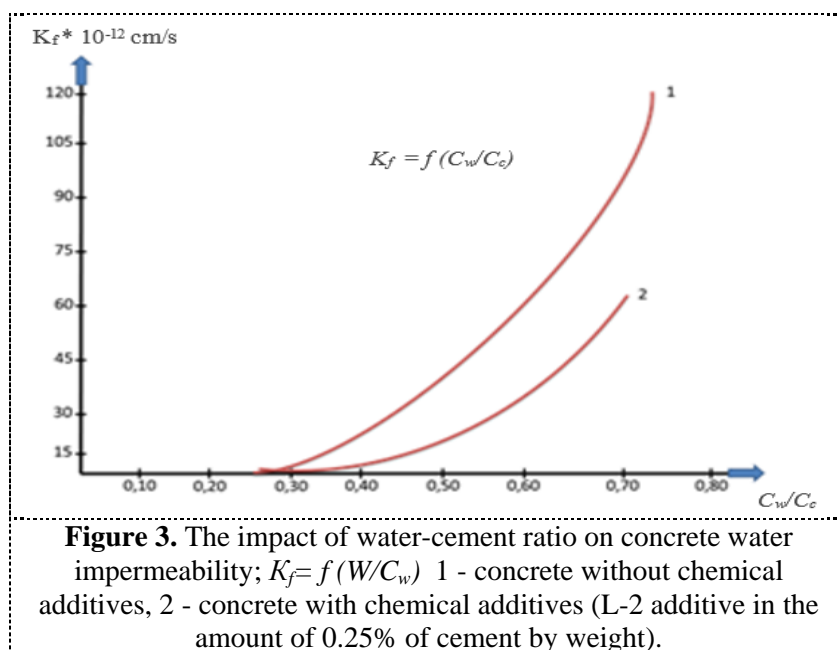
Thus hydraulic concrete water impermeability classes $W_2 \dots W_{12}$ are chosen according to state standards. Concrete water impermeability is directly related to their strength $W=f(B)$ and they are recommended for use for various elements of hydraulic structures (Table 1).

Table 1. Strength classes (B) and water impermeability classes (W) of concrete, used for various elements of hydraulic structures.

For dam spillway elements with changing water levels		For interior parts of corrugated concrete or reinforced concrete elements		For underwater and external parts of structures	
Water impermeability class	Strength class	Water impermeability class	Strength class	Water impermeability class	Strength class
W4	$\geq$B12.5	W2	$\geq$B7.5	W6	$\geq$B12.5
W6	$\geq$B15	W4	$\geq$B12.5	W8	$\geq$B15
W8	$\geq$B20			W12	$\geq$B25
W10	$\geq$B25				
W12	$\geq$B30				

Concrete macro-pore volume depends on many factors [4]. The water-cement ratio (W/C_w) can be considered the main one.

Concrete mixtures with the same (W/C_w) ratio can have different water permeability. For instance, changing the cement amount, using enough amount of densifying and plasticizing chemical additives can have a huge impact on concrete water impermeability [20, 21]. Figure 3 shows the impact of water-cement ratio (W/C_w) on concrete water impermeability.

Figure 3. The impact of water-cement ratio on concrete water impermeability; $K_f = f(W/C_w)$ 1 - concrete without chemical additives, 2 - concrete with chemical additives (L-2 additive in the amount of 0.25% of cement by weight).

It must be noted from Figure 3, that excess water amount increases with the increase of water-cement ratio in concrete preparation. This water evaporates in the process of concrete hardening as the

result of the increase of temperature and internal pressure. It leads to the formation of large size open pores and capillaries. In these cases, concrete water permeability increases significantly. In preparing concrete mixture with constant flowability, W/C_w ratio was lowered from 0.63 to 0.53 by using plasticizing agent L-2 in the amount of 0.25% of cement by weight and concrete water permeability was decreased 3 times. If hydraulic concrete W/C_w ratio is decreased by adding plasticizing agent L-2 in order to decrease hydraulic structure concrete water permeability during operation period, the absorbing properties of such concrete will be high, they can be saturated by mudding them with clay solution, thus the clay in pores and capillaries will swell and densify the mixtures in capillaries to a certain degree and concrete water permeability can be decreased by 20 to 30 times.

4. Conclusions

The effective use of land and water resources depends on the technical condition and safety of irrigation and reclamation structures in the water management sector. Water's impermeability of hydraulic concrete used in such structures plays a very important role.

Based on conducted research technological factors influencing hydraulic concrete water impermeability were analyzed and it was proven that it is possible to decrease concrete water permeability 3 times by adding L-2 plasticizing agent in the amount of 0.25% of cement by weight and decreasing water-cement ratio by 18% and to further decrease water permeability 20 to 30 times by mudding the open pores and capillaries in newly laid concrete.

Besides, recommendations are given on which class of hydraulic concrete to use in hydraulic structure construction by determining concrete water impermeability class to concrete strength relationship based on regulatory codes.

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