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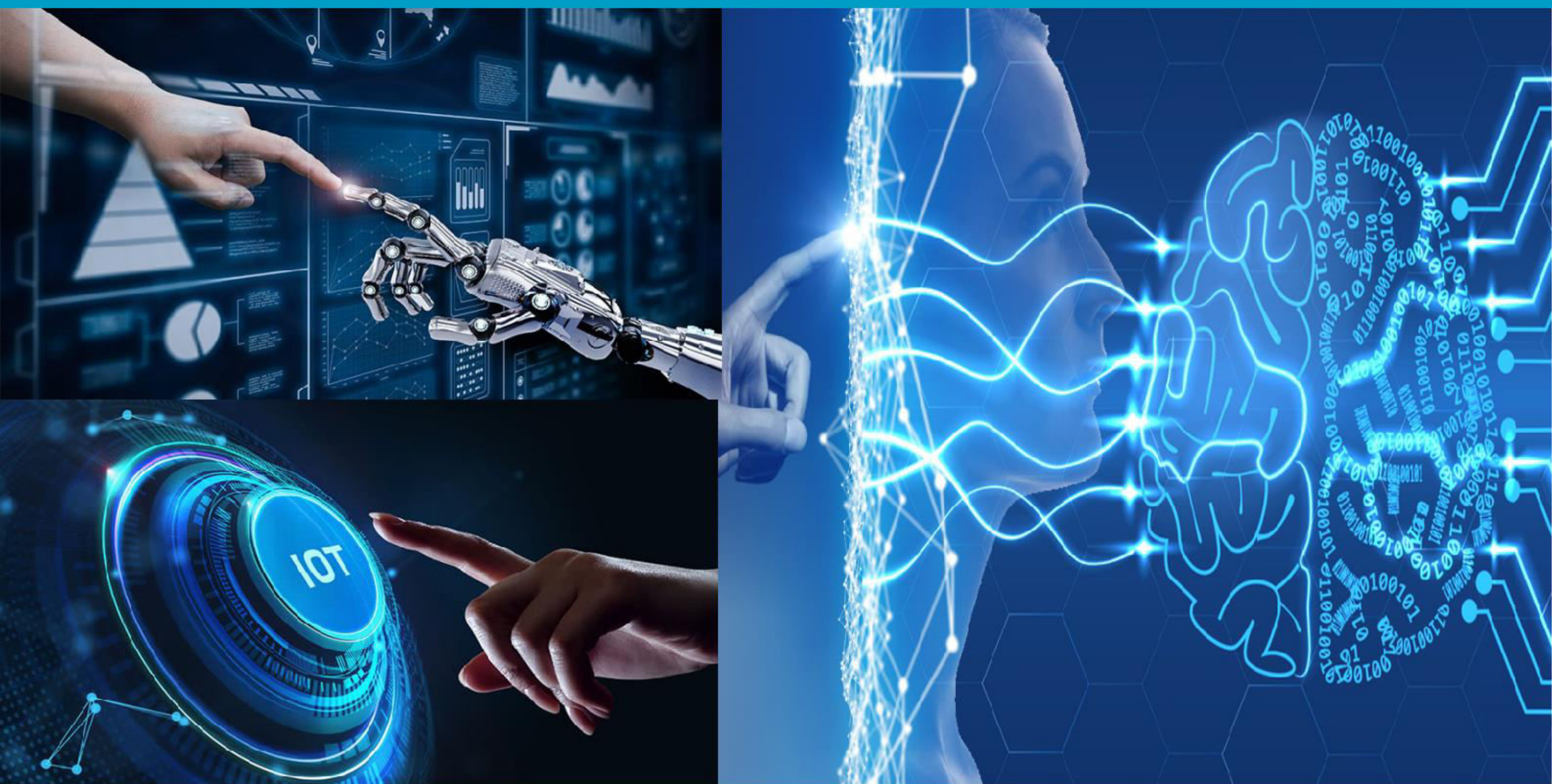

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Factors Affecting the Operational Stability of Hydraulic Concrete

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ABSTRACT: The reliability and safety of hydraulic structures largely depend on the strength and performance properties of hydraulic concrete.

Based on the results of the discussion of literature data, it was established that when selecting the composition of hydraulic concrete, it is possible to use different cements and aggregates. This means that the operational stability of hydraulic concrete depends not only on the quality of the binder, but also on the quality of the aggregates. Because, the volume of aggregates is sometimes up to 80 % of the total volume of concrete. An increase in the volume of aggregates allows for a decrease in the volume of cement paste, which leads to savings in expensive Portland cement, as well as to a decrease in shrinkage and heat release during concrete hardening, which is important for hydraulic concretes. Until recently, many researchers accepted solid aggregates as an inert material and their relationship with cement stone has not been studied in detail.

The main purpose of the study is to develop a regular effect of aggregates on the service life of hydrotechnical concrete. For experiments on this topic, Akhangaran Portland cement grade M400, with a content of three calcium aluminate (C_3A = 4.6), was taken as a binder. The chemical and mineralogical composition and indicators of physical and mechanical tests of cement are determined according to GOST 10178-76. As fine and coarse aggregates in the concrete solution, river sand was used - Chirchik sand with M_{cr}= 1.81 that meets the requirements of GOST 8736-77. As a coarse aggregate, crushed granite from the Chirchik quarry was used, which meets the requirements of GOST 8865-75. Tests of physical-mechanical, technological and operational properties of hydraulic concrete were carried out in accordance with GOST 26633-85 - Hydrotechnical concrete. The results of laboratory studies were analyzed by the method of "static processing of test results" based on Uz RST 20522-96.

According to the research results, it has been proved that if Portland cement is used in the selection of the composition of hydraulic concrete, calcium hydroxide $Ca(OH)_2$ appears in the composition of hydraulic concrete as a result of the hydrolysis of tricalcium silicate contained in cement clinker. In this case, the pH rises to 13-14. This is caused by the presence of NaOHand KOH in the composition of cement stone. In this case , an alkaline environment is formed, which initially leads to a strengthening of the bond between the concrete components. But in modern times, under the influence of an alkaline environment on the surfaces of aggregates, corrosion of concrete begins. This negative phenomenon is often observed in the zone of variable water level.

According to the results of the research, a pattern of growth in the strength of cement stone over time was established.$R_{ts.k.} = f(\tau)$,under normal conditions ($t = 20\,^{o}C$, W =90%). During air storage of samples, deformation shrinkage is observed at a relative air humidity of 80%, linear shrinkage is- 0.3 mm/n and with a decrease in air humidity to 60 and 40% linear shrinkage is 0.6-0.8 mm/n.

According to the research results, it is justified that the operational durability of hydraulic concrete is affected by various internal and external factors. One of them is the formation of a strongly alkaline medium during the hydration of a hydraulic binder. In this case, alkali is formed as NaOH and KOH . Especially NaOH causes a higher osmotic pressure and its presence in concrete leads to the formation of cracks in the body of hydrotechnical concrete

I. INTRODUCTION

The reliability and safety of hydraulic structures largely depends on the strength and performance properties of hydraulic concrete.

Concrete for hydraulic structures must not only provide the necessary strength, but also stability, since concrete is constantly or periodically washed with water during operation. Therefore, depending on the operating conditions, hydraulic concrete is also subject to requirements for water resistance, water tightness and frost resistance[12] .

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To ensure the necessary stability of hydraulic concrete, the tensile and shrinkage indicators are also normalized. At the same time, the operational properties of hydraulic concrete are ensured. By proper selection and use of raw materials, special properties such as water resistance, water tightness and frost resistance of concrete are ensured. When choosing a binder for hydrotechnical concrete, it must be borne in mind that Portland cement in its pure form is unable to provide the necessary water resistance of concrete, which is constantly or periodically under water. The main reason is the high content of calcium hydroxide $Ca(OH)_2$ in cement hydration products, which is highly soluble in water, which leads to leaching of cement stone, as well as a gradual decrease in its density. Until the last year in concrete technology it was considered that aggregates of hydrotechnical concrete are inert in relation to cement stone [16] . Such an idea arose at a time when normal-hardening concrete was predominantly used on aggregates of quartz sand and igneous crystalline rocks, which, under these conditions, are indeed inert.

Many dense and porous aggregates are deformed under the influence of internal and external factors, with the contact zones being destroyed first of all and the adhesion of the aggregate to the cement stone is weakened. These phenomena lead to the destruction of concrete structures or to the deterioration of the performance properties of hydraulic concrete.

In scientific works, most researchers [17] describe in sufficient detail the physical properties of aggregates and their influence on the structure and strength of concrete, on chemical interaction with cement minerals. Changes in the properties of fillers under the influence of internal and external factors have not yet been studied in detail and are considered only in individual cases.

Aggregates are an important component of ordinary heavy and hydraulic concrete, as they occupy up to 80% of its volume. The construction, technical and operational characteristics of concrete depend on the type and properties of aggregates [18] . With an increase in the number of aggregates in concrete, the volume of cement paste is multiplied. And cement in concrete is the most expensive and scarce component. High-quality fillers creating a rigid frame increase the strength and modulus of concrete deformation. During hardening of conventional and hydrotechnical concretes, the particle size of aggregates does not usually change. At the same time, the cement stone shrinks in the range of 0.1 - 0.2% of the original size. Therefore, the aggregate perceives the shrinkage stresses created by the cement stone and, as a result, reduces the shrinkage of concrete several times compared to the shrinkage of the cement stone. This is very important for hydrotechnical concretes, where water resistance and frost resistance are required. The use of dense, durable aggregates with special properties makes it possible to prepare such hydraulic concretes that are waterproof in aggressive environments at varying temperatures and under the influence of other external and internal factors.

II. MATERIALS AND METHODS.

Local building materials were used to study the factors affecting the operational durability of hydrotechnical concrete. For carrying out experimental research work, the most common Akhangaran Portland cement M400 in Uzbekistan was adopted. The chemical and mineralogical composition and the results of physical and mechanical tests of cement (GOST 10178-75) are shown in tables 1 and 2.

Chemical and mineralogical composition of cement.

Table 1

Factorybrandofcement	Mineralogicalcomposition, wt.%				Chemicalcomposition, wt.%					
	C_3S	C_2S	C_3A	C_4AF	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O $+K_2O$
Akhangaran portland cement M400	56	eighteen	4.6	thirteen	21.2	6.1	4.27	64.2	1.90	0.98

The results of physical and mechanical tests of Akhangaran Portland cement M400.

table 2

No	Characteristics of cement	Unit of measurement	The value of indicators
1.	Normal density of cement paste	%	25.8
2.	Setting time :		
	start	hour.min	2.57
	the end		4.28
3.	Specific surface area	m^2/g	2.93
4.	Compressive strength (GOST 310.4-76) after		
	3 days	MPa	24.8
	7		32.3
	28		39.8

As fine and coarse aggregates in mortar and concrete, the following were used:

- Chirchik river sand with M_{cr} = 1.81, meeting the requirements of GOST 8736-77 "Sand for construction work. Specifications»

- granite crushed stone, fraction 5-20 mm, Chirchik quarry, corresponding to the requirements of GOST 8267-75 " Crushed stone from natural stone for construction work".

Granulometric composition of sand

Table 3

No	Residues on sieves in %	Mesh sizes on sieves (mm)						
		5	2.5	1.25	0.63	0.315	0.14	bottom
1.	private remains	-	0.50	0.6	13.1	43	41	1.7
2.	Complete balances	-	0.50	1.1	14.2	57.2	98.2	99.9

Sand characteristic

Table 4

No	Sand characteristic	Unit of measurement	indicator
one	Size modulus	-	1.81
2	Bulk density of dry sand	t/m^3	1.49
3	Density of sand particles	t/m^3	2.63
4	emptiness	%	42
5	The content of clay impurities	%	1.1-1.3

According to the task set, the experiments take into account the technical requirements for hydraulic concrete. The requirements for the materials of hydrotechnical concrete depend on the operating conditions in the structures. For the underwater part of the structure in concrete, pozzolanic Portland cement and Portland slag cement are used as the most water resistant. For concrete located in the zone of variable water level, sulfate-resistant Portland cement is used. It is allowed to use Portland cement with a mineral content of C_3A up to 8%.

The consumption of cement per 1 m^{3} of hydraulic concrete is assumed to be 5% more than described in the recommendation, relative to the minimum consumption of cement to obtain a concrete mixture for ordinary heavy concrete.

Tests for the mobility of the concrete mixture were carried out according to the standard method according to GOST 10181-76 "Heavy concrete, Methods for determining the mobility and stiffness of concrete mixtures".

Physical-mechanical, technological and operational properties of hydraulic concrete used in hydraulic construction were tested according to state standards (GOST 26633-2015. Hydraulic concrete) and obtained results were evaluated according to "Statistical processing methods of test results" (Uz RST 20522-96). 70x70x70 mm concrete cubes prepared of cement – sand mix at 1:3 ratio are used for tests for various conditions. Ohangaron plant M400 Portland cement with 0.83% Na_2O oxide was used as bonder and sandstone with 4% opal (SiO_2nH_2O) was used as fine filler. The filler particle maximal diameter is 2.5 mm. Size modulus is $M_к = 1.81$.

In research hydraulic concrete composition was designed according to "absolute volume method" and concrete component were considered as "absolutely dry state". When testing operational properties of hydraulic concrete, natural water content of concrete components were determined and corrections were input to the composition determined in laboratory conditions [2; 9;14; 23].

III. RESULTS

Concrete was prepared for the study from 1:3 ratio cement-sand mix. Ohangaron plant M400 Portland cement with 0.83% Na_2O oxide was used as bonder and sandstone with 4% opal (SiO_2nH_2O) was used as fine filler.

The mix sample sizes were 70x70x70 mm. Maximal diameter of fille particles was 2.5 mm and size modulus $M_к = 1.81$. The change in strength of cement mix in time during curing is shown in Fig.1.

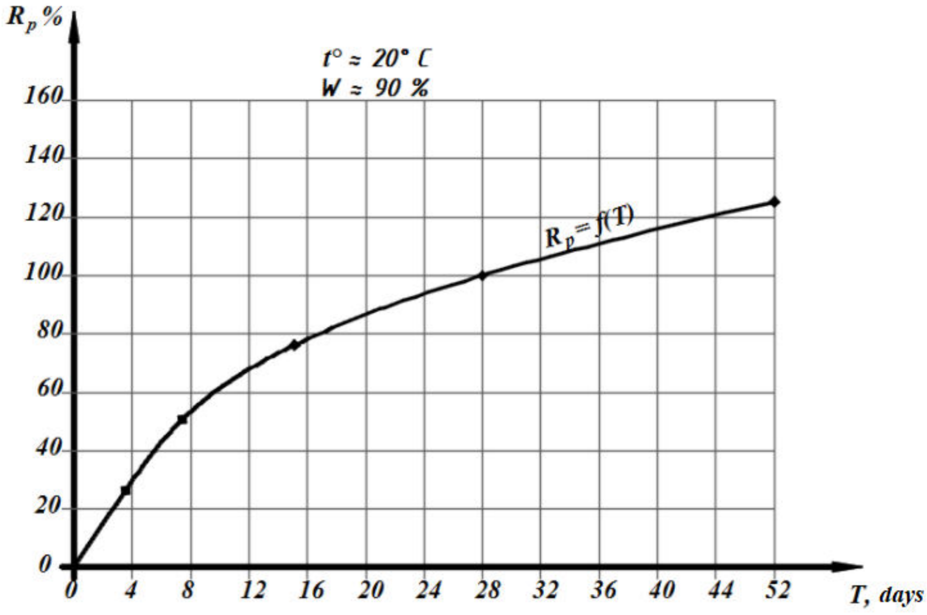

Figure 1. Plot of change of cement mix strength over time

Source:["Compiledbytheathors"].

The concrete mix samples were stored in various conditions and their shrinkage and swelling deformations were analyzed. The experiments show that shrinkage deformations in cement mix samples stored in open air were not that high. At relative air humidity of 80% shrinkage deformations were 0.18…0.31 mm/m, at 60 and 40% relative humidity, those values were 0.61 and 0.82 mm/m, respectively the Fig.2 below shows the plot of deformations of cement mix samples at various storage conditions.

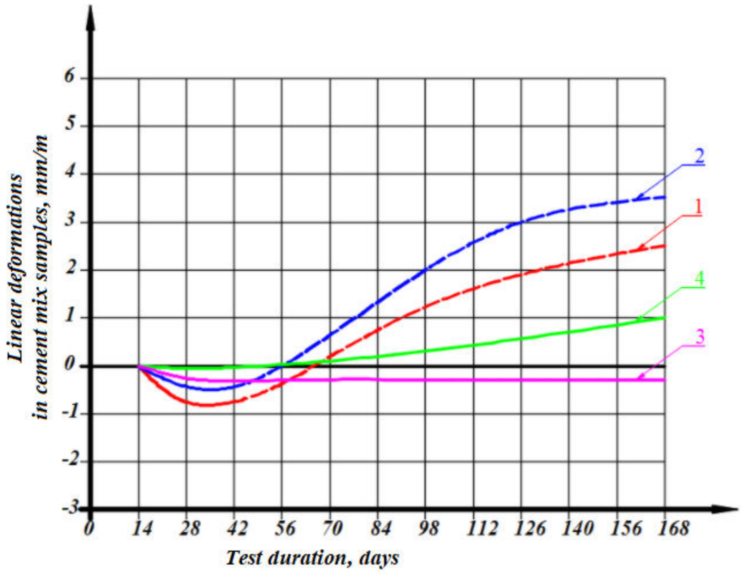

Figure 2. Plots of linear deformations of cement mix samples stored in various conditions: 1-at natural relative air humidity 40%; 2-at relative air humidity 60%; 3-at relative air humidity 80%; 4-at relative air humidity 95%.

Source:[“Compiledbytheathors”].

Note: solid line (–) is for sample kept in open air, dashed line (- - -) is for samples kept in water.

From Fig.2 plot it can be concluded that linear deformation of cement mix is directly related to relative humidity of air it is kept in. When stored in relative air humidity of 90-95%, swelling deformations take place in samples. But the value does not exceed 1.43 mm/m.

When samples are kept in water, swelling deformations started after 14 days. Linear swelling deformations in samples initially kept in open air, then inserted in water were about 0.3…0.6%, and cracks formed in samples. Initially, swelling deformation in samples kept in open air occur very quickly (Figures 1 and 2).

Based on the studies, it should be stated that the effect of NaOH and KOH hydroxides in formation of corrosion in concrete is noticeable. Industrial waste (active amorph shaped or silica glass) which are free silicon oxides react with above mentioned hydroxides and may increase corrosion. Besides, concrete prepared of fillers comprised of minerals which can react with the hydroxides, may also have strong corrosion [5;21;25].

If the mix does not have free $Ca(OH)_2$, the reaction of SiO_2 with above mentioned alkali does not do a noticeable danger. If the system is saturated with $Ca(OH)_2$ solution, large points of white gel shaped matter will appear in cement rock and filler. This process is very complicated and depends on many factors, including mineralogical composition of fillers and their chemical properties, cement’s chemical properties, filler/cement rock ratio, and other factors [1].

Therefore many scientists consider that osmotic pressure at cement rock and filler connection boundary is the main mechanism of this kind of corrosion, where alkali silica form as the result of interaction between ROH and SiO_2 or silica at swelling phase.

Initially concentrated R_2O $nSiO_2$ mH_2O solution formed at connection boundary are covered with hydrosilica shell. This shell has semiconduction property and passes Na^+, K^+, OH^-ions through itself. However, it keeps large ions of silica and polysilica acids in itself. As a result large concentration alkali silica zones form in the boundary between cement rock and water molecules, and large osmotic pressure (15…17 MPa) occur at these location, because the concentrations of alkali silica at these zones are 4 times larger than initial SiO_2 n H_2O volumes.

Therefore, stresses occur around filler particles at initial stages of corrosion in concrete and these internal stresses grow quickly in boundary zones due to osmotic pressure and result in the erosion of hydrotechnical concrete [3;13].

The previously studied negative effect of free $Ca(OH)_2$ is due to significant changes in the water permeability and physical and mechanical properties of the cement stone of water-proof concrete due to reactions of alkali hydrosilicate with calcium hydroxide; during these reactions, the cement stone surrounding the silica grain is compacted and loses its ability to plastic deformation.

It was found that with an increase in the degree of polycondensation of alkaline silicate and the formation of concentrated gels, the osmotic pressure decreases, and at the same time, a new factor appears - the pressure of gel swelling due to the thickening of the hydrated film aroundreleased colloidal particles. As a result, internal stresses in the contact zone increase significantly. When the internal pressure on the shell of compacted cement stone exceeds its tensile strength, the cement stone shellcollapses and several cracks appear through which a viscous alkali silicate solution is squeezed out.The sources of NaOH and KOH are the alkaline minerals of Portland cement, alkali metal salts introduced into the composition of concrete in the form of special additives, such as hardening accelerators, antifreeze and others. It was found that NaOH causes a higher osmotic pressure and its presence in the composition of cement stone is considered more dangerous for water-proof concretes. In the publications of researchers, it was shown that alkali metal salts affect this type of corrosion in different ways [6]. More dangerous are the salts of strong acids, such as hydrochloric, nitric and nitrogenous acids, in the process of interaction with Ca (OH)2and calcium hydrosilicates, the binding of Ce, NO_3,NO_2 -anions into poorly soluble compounds does not occur. These anions accelerate the processes of polycondensation of alkali silicates and coagulation of colloidal solutions.

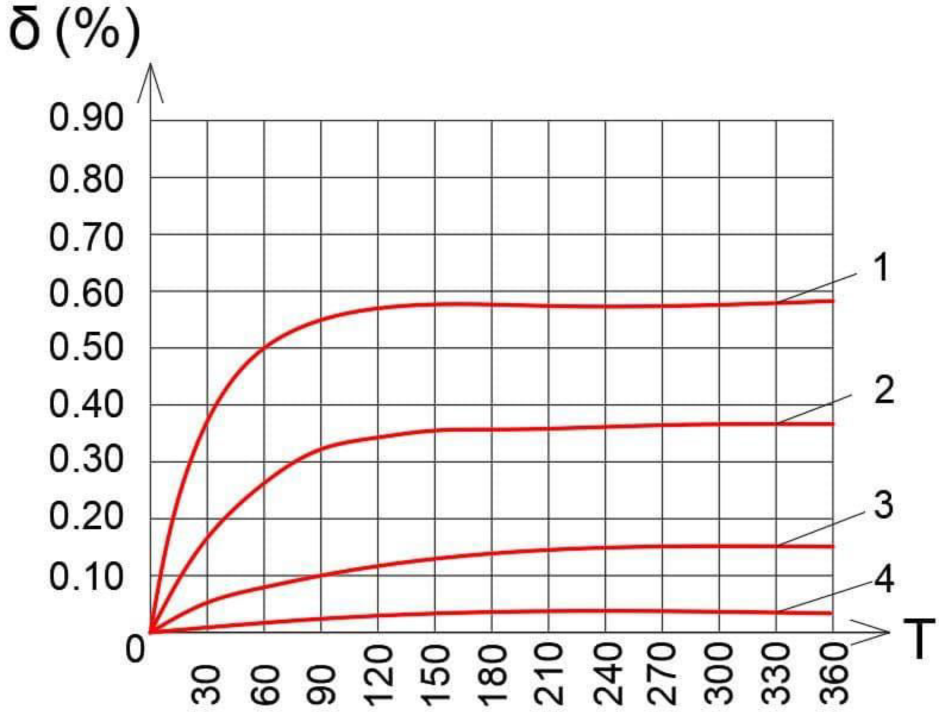

Fig 3 Linear deformation of the expansion of samples from the solution with fillers:

1 - opal; 2- chalcedony; 3 - cristobolite and tridymite; 4 - quartz.
T- is the storage duration of samples (days). $^{\delta}$ – linear expansion deformation, (in %).
Source:[“Compiledbytheathors”].

As seen from the graphs (Fig. 3), the maximum deformations are typical for samples with opal ($^{\delta}$= 0.58%) and the products of its partial crystallization - chalcedony ($^{\delta}$= 0.38%). High-temperature modifications of silica - cristobolite and tridymite - have a lower reactivity and cause moderate expansion of samples ($^{\delta}$=0.13%). Quartz samples almost do not expand with time, and the maximum linear expansion after 360 days of storage is only 0.03%.

For sedimentary rocks, the presence of opal is of primary importance, as it is dangerous even at a low content in the mass of aggregate. Opal crystallization, which is characteristic of siliceous inclusions in carbonate rocks, with the transition to chalcedony and a proportion of quartz, significantly reduces the reactivity of such a filler.

IV. DISCUSSION

Concrete and reinforced concrete is one of the most important construction materials in construction of hydraulic structures, their reconstruction and repair. That is why, reliability of hydraulic structures mostly depends on physical-mechanical and operational propertiesof concrete used in them [12].

Various types of cement and fillers can be used in designing the composition of hydraulic concrete for construction of hydraulic structures. Various researches has shown that if concrete consists of 20% cement rock, the rest 80% constitute fillers [16]. Therefore, physical-mechanical and operational properties of concrete used in hydraulic structures depend both on cement rock and filler quality characteristics. Mostly dense and heavy concrete is used in construction of hydraulic structures. The reason for it is that dense and strong fillers in concrete mix are bonded together with cement rock and make up a rigid structure. That, in turn increases the strength and modulus of deformation of concrete. The dimensions of filler particles almost don't change during concrete curing period. However, shrinkage of cement rock is around 0.1…0.22%. This is why during the process of curing filler particles receive the loads from cement rock shrinkage and decrease concrete shrinkage several times compared to cement rock shrinkage [17]. Based on this, studying the influence of fillers on concrete operational stability is an important issue, and it is considered to be the main goal of research [3;4].

Various types of locally found fillers are used in large hydraulic structures. Besides, environment, chemical reagents and other factors influence noticeably on hydraulic concrete structures. Most fillers decrease in size and volume due to acid and salt corrosion. It results in initial erosion in cement rock and filler connection zones and the connection between filler and cement rock starts to slowly disappear [6;15].

Also, external environment has a negative influence on operational stability of concrete. Air temperature has a certain influence on both outside and under water parts of hydraulic structures. High temperature in dry environment result in swelling of concrete filler particles and in internal stress in concrete, which result in various size cracks on its surface. These negative conditions finally result in the decrease of operational stability of concrete. Therefore, it is reasonable to divide factor affecting concrete stability into two categories when studying concrete operational stability.

First category may include internal factors, the second includes external factors. Internal factors are mainly related with cement rock in concrete composition and aggressive impact of liquid calcium, sodium, potassium hydroxide and alkali metal carbonates can be included in this category.

If Portland cement is used as bonder in preparing hydraulic concrete, calcium hydroxide formas the result of three silica hydrolysis from filler or cement clinker. In some cases if there are phases of alkali nature in cement clinker, pH of cement rock may increase up to 13…14. NaOH and KOH are the main reason for it. Main component of liquid phase of cement rock is SO^2_4 ion, whose two molecules are formed as the result of breaking of gypsum, alkali sulfates and calcium hydrosulphoaluminates. The studies show that cement rock curing result in formation of new layers in contact boundary of filler and cement rock, which increases the bond between concrete components. At the same time, in certain cases corrosion of fillers may take place as the result of long duration impact of alkali environment.

In concrete technology most of the fillers are considered to be inert with respect to cement rock. However, in construction of hydraulic structures, concrete and reinforced concrete works comprise the large portion and various local fillers are used in it. Therefore, in construction of hydraulic structures it there is a need to study sufficiently the physical-mechanical and mineralogical properties of the fillers in order to use them effectively and to increase the strength, frost resistance and decrease water permeability of concrete structures. Besides in order to save consumption of cement, which is the most expensive component of such structures, waste from "Heat power station" may be used, that is ash and slag and metallurgy slags as additions to bonders or fillers [6].

In these cases, these additional fillers may react solutions while curing in air-water or water environment. Substances, which form during bonder curing process react with fillers and increase the mechanical properties of the concrete. As a result, it becomes possible to decrease cement use without reducing concrete strength class. However, if these processes are not studies carefully, they may result in worthening of physical-mechanical properties of concrete. Therefore, it is very important to study chemical reactions taking place between fillers and cement bonders during their curing process. These processes are very important in studying the main operational property of concrete, which is corrosion processes. Corrosion in strong alkali environment are mostly stronger in hydraulic structures since they are in water and humid environment. Studies show that corrosion takes place more aggressively when water level changes often in hydraulic structures, because in these zones concrete is saturated and change in water level takes place more often than freezing and thawing cycle. Usually concrete outside water these type of corrosion almost is not observed. The main reason of concrete erosion in points were water level changes, is cracks, which facilitate concrete erosion further [7;18].

V. CONCLUSIONS

Withing the research work the influence of alkali solutions occurring in hydraulic structures was studied. The main reason of alkali environment formation is NaOH and KOH hydroxides of alkali mineral in Portland cement used as bonder for hydraulic concrete. Besides, unreasonable use of certain chemical additives (fast curing, anti-frost, etc.) may result formation of NaOH and KOH hydroxides due to the alkali salts in those additives, because NaOH may form a strong osmotic pressure. Thus, it would be reasonable not to allow for strong alkali environment in preparing hydraulic concrete and to correctly choose bonder to decrease concrete corrosion. Therefore it is important to sufficiently study the mineralogical composition and chemical properties of bonders and use inert fillers as much as possible.

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