DURABLE FIBROUS CONCRETE FOR THE THIN-WALLED HYDROTECHNICAL STRUCTURES

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Abstract:

Durable fibrous concrete has been obtained for the thin-walled hydrotechnical structures. Complex modifiers consisting of sealing additives, fluidifier and filling compound have been developed which allow to reduce the capillary porosity and to create the system of closed pores with required size. It is shown that for the redistribution of local moist deformations in the thin-walled hydrotechnical structures it is necessary to provide the transmission of deformations by volume through fiber three-dimensional reinforcement which is not corrodible. The joint use of fibre-reinforcing polymer and filling compound increases the impact resistance of concrete by 3 times, fracture strength more than 40%, freeze resistance for 150-200 cycles and also reduces the shrinkage and swelling in process of exploitation. High-technology and durable fibrous concrete has been obtained with classes B60 and higher with water resistance up to W16 and freeze resistance more than F600 which allows to reduce the thickness of construction of hydrotechnical structures. The proposed modified fibrous concrete has been used for floating docksmanufacture and thin-walled hydrotechnical structures.
Keywords: fine-grained concrete, hydro-technical buildings, dispersion reinforcing, micro-fillers, water-tightness, frost-resistance, crack resistance, experimental-statistical modeling.

1 Introduction

In modern hydrotechnical, hydroeconomic and shipping building thin-walled ferroconcrete constructions are widely used [1]. The sidewalls of the channels (fig.1.a) and the water-supply constructions are made 8-12 cm thick, while the bodies of floating ferroconcrete structures (fig.1.b) are from 8 to 16 cm thick with the quantity of reinforcing steel to 800 kg/m^3. The specific character of the material work in such constructions is conditioned by the one-sided effect of the operational workloads: hydrostatic pressure, dynamic impact of liquid and ice, freezing and melting, moistening and drying, chemical exposure, fouling by algae and living organisms, frequent change of temperature. That is the major factors providing the durability of thin-walled hydroeconomic constructions are water and frost resistance of concrete [2]. Besides, it is necessary to take into account the emergence of humidity gradients, the temperature and concentration of chemical agents along the height and the section of the constructions.

The temperature and humidity gradients are able to generate peculiar "waves" of deformations in the material of constructions. The total effect of the alternating

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deformations leads to the change of structural material data and lowering its operational characteristics. It is necessary to provide the transference of alternating deformations along the bulk of the construction through the reinforcing of the material not subject to fibre corrosion for redistribution of local deformation.

(a)

(b)

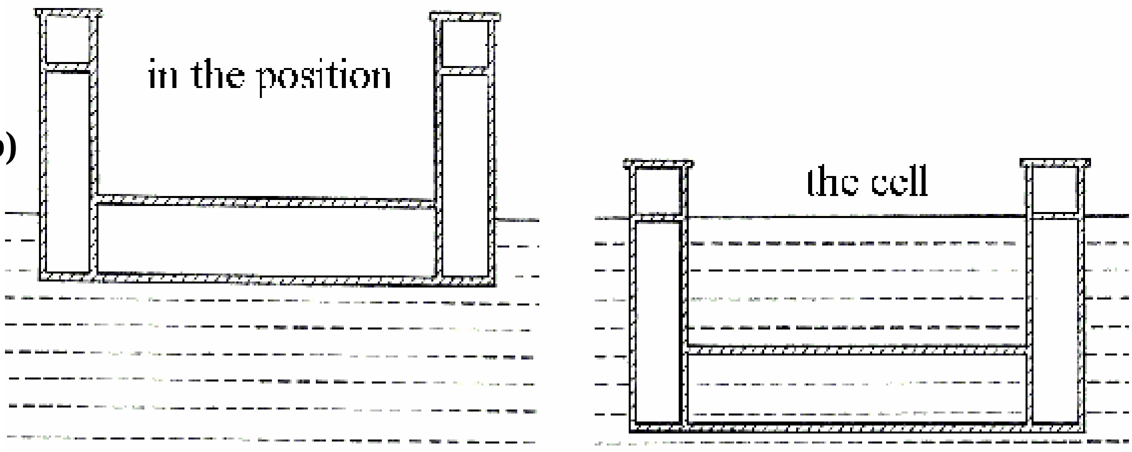

Fig. 1. The thin-walled concrete facing of the irrigation canal (a) and the scheme of functioning of floating dock (b).

2 Caption

The mechanism of formation of local and integral temperature and humidity deformations in concrete of thin-walled hydrotechnical constructions has been analysed. The measurement of moisture content in the material (fig. 2.a) causes individual development of humidity deformations in each section of the construction (fig. 2.b). The concrete undergoes swelling deformation in the subaqueous zone, which turn into deformations of shrinkage of the upper zone (fig. 2.c). This causes uneven distribution of humidity deformations along the height of the making. As the water level can vary, the values and the directions of the humidity deformation effect can also change. In the concrete there appear the “waves” of humidity deformations which flow along as well as crosswise the item. From the point of view of frequent change of humidity deformations the zone of variable water level is the most dangerous.

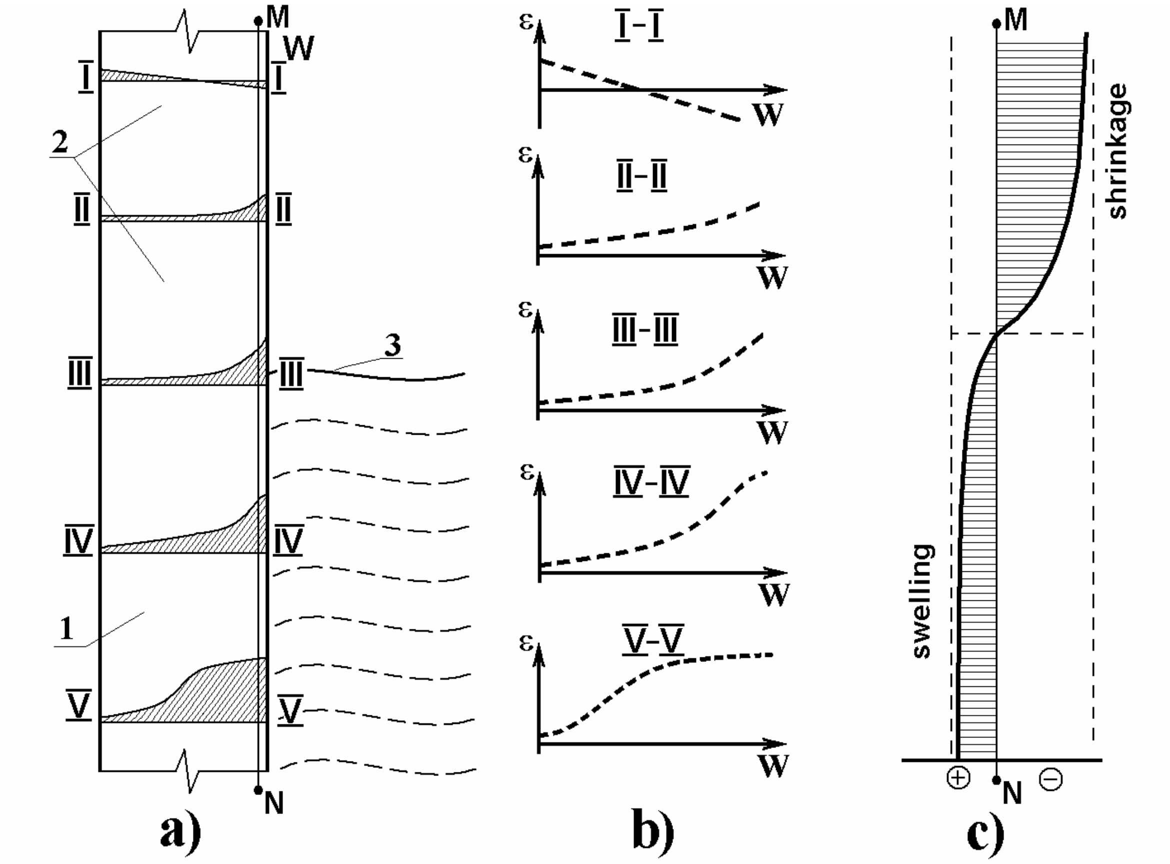

Fig.2. The principal scheme of humidity distribution and humidity deformations inside the constructions of a floating structure: a – the fragment of the construction; b – the distribution of humidity deformations along the sections of the construction; c – the distribution of humidity deformations along the height of the constructions.
1 – fragment of the construction; 2 characteristic sections; 3 – variable level of water; MN – outer layer of the material of the construction.

That is in the process of the maintenance concrete structure in the construction undergoes continuous changes, which are to be taken into account when designing its composition. For the prognostication and providing durability of concrete of thin-walled hydrotechnical constructions it is necessary to take into account:

- the composition of concrete. Owing to the specific of the operation of concrete it is necessary to apply sulphate-resistant Portland cement and filling;
- preparation technology. When providing high activity of the mix and high physical-mechanical characteristics occlusive and plasticizing additives and environment resistant fibre are to be applied;
- the structure forming at the initial stage of the production of a thin-wall construction. The most important structural characteristics can be named the general bulk and the type of capillary-porous space;

the change of the structure as a result of operational exposure (exposure to water, capillary suction effect, salt accumulation, etc.), and also the processes going on in the structure of modified concrete. Besides, it is necessary to take into account single out interstice occlusion at the expense of the effect of special additives and interstice occlusion by corrosion products [3]. Besides it is necessary to take into account late hydration of cement, which is conductive to consolidation of concrete structure, i.e. is the main source of self-healing. Humid conditions of operation of hydrotechnical constructions are optimal for its manifestation.

In order to lower the local gradients of alternating humidity and temperature deformations of concrete it is necessary to create conditions for getting the network of closed interstices and capillaries of similar size on condition of general porosity lowering. One of the ways to get necessary structure is the application of special multifunctional complex additives.

In order to redistribute local deformations it is necessary to provide the measures of transmitting alternating deformations along the bulk of the construction. It is possible to refer to such measures the volumetric reinforcement of material by environment resistant fibre.

Hereby the improvement of the complex of physical-mechanical characteristics of concrete for thin-walled floating and hydrotechnical constructions can be achieved by creating the structure with the network of fine interstice with lowered general and capillary porosity with the additional application of dispersed reinforcement. For the effective use of dispersed reinforcement by fibre in combination with concrete materials for floating constructions and various modifiers it is necessary to optimise the structure of composite materials and the method of their preparation.

The influence of the two types of polypropylene fibre was studied: they used Fiberfresh fibre of 200 micrometers in diameter and 13 mm long in A Series, and Baukon fibre in B Series.

The four-factor experiment was carried out. The following factors of fine-grained concrete mix varied:

X_1 - the quantity of sulphate-resistant Portland cement, from 500 to 700kg/m³.

X_2 - the ratio breakstone/sand, from 1.6 to 2.2.

X_3 - the quantity of filling (crushed sand of specific surface of 300 m²/kg), from 0 to 8 % of cement mass.

X_4 - the quantity of Baucon fibre (19 micrometers in diameter, 12 mm long), from 0 to 1.2 kg/m³.

The complex additive Penetron A + super plasticizer C-3, 2% and 8 % from the cement mass, respectively, designed by us, was injected into all the mixtures [4]. All the mixes had similar mobility from 16 to 18 cm.

Strength characteristics of fibrous concrete were tested in aqueous and dry conditions. The positive influence of the filling was detected: owing to the injection of 8 % of ground sand the compression strength of concrete is increased by 10 - 15 MPa and the tension strength when buckling by about 1.5 MPa.

The fibers have practically no influence on the strength of concrete when pressing, but improve its stretching resistance. Owing to the injection of fibre, stretching resistance increases by 1 – 1.5 MPa, which is explained by the reinforcing influence of fibre.

Besides, the application of fibre and crushed sand allows to heighten the dynamic resistance of the composite, what is very important for thin-walled constructions. Fibrous concretes with filling show triple impact resistance and greater fracture strength than concrete materials of analogous structure without fibre and filling.

One of the main tasks of the testing was the examination of the influence of modified fibre concrete on its water resistance. All its structures had a high level of W, what was provided by the presence of the additive Penetron + C-3 in its structure. The highest water resistance, to W20, was show by the compositions with high breakstone/sand ratio and the maximum level of filling, which is explained by the improvement of capillary-porous composite structure (fig.3.a). And the injection of fibre does not affect the water resistance of concrete.

The influence of the quantity of concrete, breakstone/sand ratio, the quantity of filling and polymeric fibre Baukon on the frost resistance of concrete is described by the experimental-statistic model (s_e = 15 cycles):

$$
\begin{array}{llllll}
F\ (\text{cycles}) = 585.3 + 24.9x_1 & \bullet & \bullet & \bullet & \bullet & \\
\quad + 6.2x_2 & \bullet & & - 12.3x_2x_3 & + 6.3x_2x_4 & \\
\quad + 29.9x_3 - 25.9x_3^2 & & & & + 8.4x_3x_4 & \\
\quad + 46.8x_4 - 19.0x_4^2 & & & & & (1)
\end{array}
$$

The chart built according to this model and reflecting the influence of breakstone/sand ratio, the quantity of fibre and filling on frost resistance of concrete is shown in fig.3.b. And the quantity of cement is fixed at the level of 600kg/m³ (x_1=0).

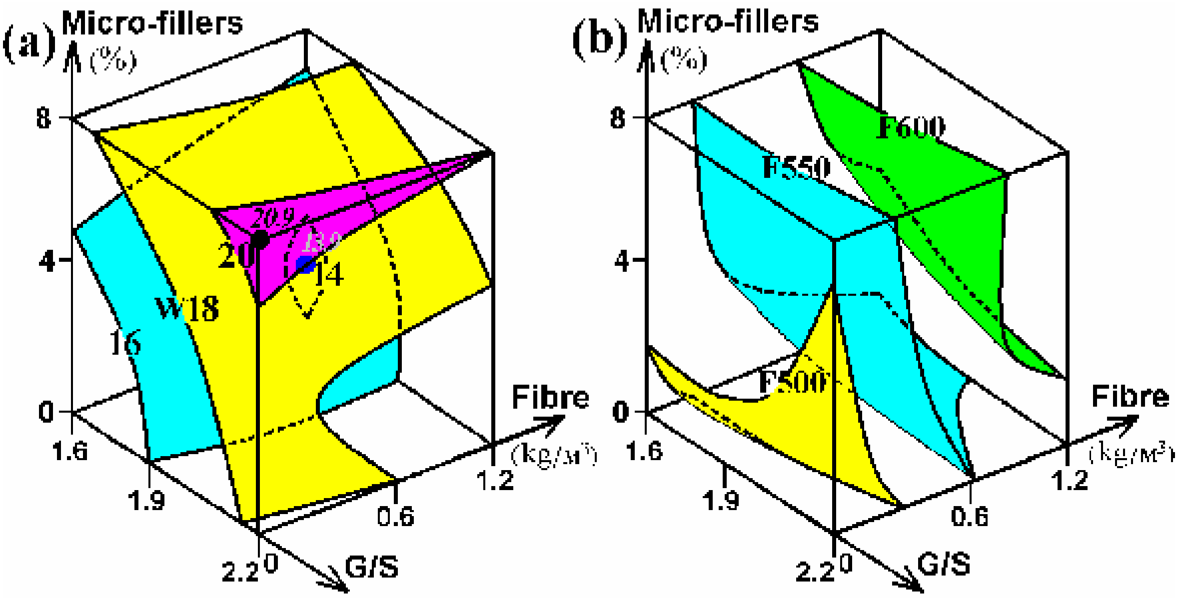

Fig.3. The influence of breakstone/sand ratio, the quantity of fibre and filling on water resistance (a) and frost resistance (b) of concrete.

The analysis of the charts allows to note that owing to the injection of filling (crushed sand) frost resistance of the composite increases by 50 – 100 cycles, irrespective of the level of other factors. Frost resistance increases more substantially, by 100 – 500 cycles, owing to the use of dispersed reinforcement. For the compositions with the quantity of Baukon fibre from 1 to 1.2 kg/m³ the level of frost resistance reaches the F600 grade (with the simultaneous injection of the filling). The positive influence of fibre on frost resistance is explained by the reinforcement effect of its fibers, perceiving the tension in the structure when frosting and melting.

The change of concrete and fibrous concrete properties is explained by the decrease of general bulk of open interstice and the increase of interstice homogeneity according to sizes. Owing to the use of the complex additive with the filling it is possible to produce microporous ($\lambda \leq 0.5$) shipbuilding concretes and fibrous concretes with high level of interstice homogeneity ($0.7 < \alpha \leq 1.0$), as it is shown in tab.1

Tab.1. The change of interstice structure of modified fibrous concretes.

Interstice characteristics	Pure concrete	With the additive C-3	With complex additive Penetron + C-3	With the filling and complex additive	With fibre, the filling and complex additive
General open porosity %	10-11	8.5-9	7-8	7-8	7.5-8.5
Average size of interstice λ	2-4	0.6-1	0.4-0.6	0.4-0.5	0.4-0.5
Homogeneity of interstice by size α	0.3-0.5	0.6-0.7	0.7-0.8	0.8-0.9	0.8-0.9

Hereby, the use of the complex additive [Penetron A + superplasticizer C-3 + filling] in combination with bulk dispersive reinforcement by polymeric fibre [5], is an effective method to raise the level of longevity of the material of thin-walled constructions, which undergo one-sided hydrostatic pressure.

The results of testing are introduced into the production. The Recommendations on preparation technology and use of heavy shipbuilding concrete in the building of sea floating ferroconcrete and composite constructions. The given compositions of modified concretes were used in the building of floating docks (fig.4) at “Pallada” plant in the Ukraine, and also in the restoration and building of thin-walled constructions hydrotechnical works of melioration. The results of this work were taken into account in the formulation of some normative documents.

3 Conclusions

It is shown that it is possible to lower the gradients of local alternating humidity deformations owing to the introduction of complex modifiers composed of plasticizing and occlusive additives and fillings. It is necessary to provide the transference of alternating deformation along the bulk of the construction through the bulk reinforcement of the construction material by fibre.

The application of the complex modifiers and filling allows lowering the open porosity by 10 – 20 % and achieving the lowering of the average interstice size by 1.5 – 2 times, which allows to get microporous concretes and fibrous concretes with high interstice homogeneity for thin-walled floating and hydrotechnical constructions.

Fig. 4. The floating dock with load-carrying ability of 8,000 tons.

The frost resistance of concrete owing to the application of dispersive reinforcement increases by 100 – 150 cycles, owing to the introduction of the filling – by 50 – 100 cycles. The maximum frost resistance of fibrous concrete surpasses the grade F600. Water resistance of all the tested compositions is in the limits from W14 to W20.

The application of fibre allows to heighten the fracture strength of concrete and dynamic strength of concrete. Fibrous concrete with filling demonstrate triple impact resistance than concretes of the analogous compositions without fibre and filling.

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