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INFLUENCE OF WATER SATURATION OF CONCRETE OF PIPES ON THEIR RESISTIBILITY

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Summary. The results of research of influence of unequal water saturation on performance characteristics of modified concrete of special purpose are introduced in this article. There were defined the dependences of concrete resistibility on the degree of saturation of liquids of different polarity, including water. It is shown that one of the directions of achievement of project performance characteristics of concrete can be an active physical chemical influence on the process of structure forming of cementing matrix of concrete and the development of the ways of increase of homogeneity spreading of internal voltage in it.

Key words: modified concrete, water saturation, resistibility, coefficient of softening.

ACTUALITY OF RESEARCHES AND PROBLEM DEFINITION

Resistibility of concretes, including any other stone materials, is coming down at water saturation. This happens in consequence of the fact that micro crack formation is reduced at adsorption by hard body of polar liquid [Gagarin 1999]. The degree of reduction of material's resistibility depends on its physical mechanical properties and is characterised by the coefficient of softening.

The important role play the other phenomena and factors in concretes besides adsorption effect, complicating dependence of concrete resistibility on its degree of water saturation [Alexeev, Ivanov, Modry, Shysl 1990, Komokhov, Latypov, Vaganov, Latypova 1999]. In this connection the resistibility of water saturated concrete proves to be even higher than the resistibility of dry concrete of the same composition under certain conditions. That fact that it was not taken into consideration the whole possible complex of conditions during the research of the resistibility of water saturated concrete led to contradicting results. Thus, for instance, it was observed in experiments [Polak 1986] the increase of resistibility of concrete with the increase of its humidity, and in experiments [Kladko 1983] – the decrease.

PURPOSE AND OBJECT OF INVESTIGATION

The purpose of this work is in the investigation of the influence of irregular water saturation on service characteristics of modified concrete of special purpose.

MATERIALS AND RESULTS OF INVESTIGATION

Having investigated the dependence of the resistibility of the samples of cement sandish matrix drilled out of the concrete on the degree of its saturation by the liquids of different polarity including the water, there were established the possible reasons of getting contradicting results by carried experiments. The degree of saturation has been varied from the zero to the maximal pore filling with the liquid (fig. 1).

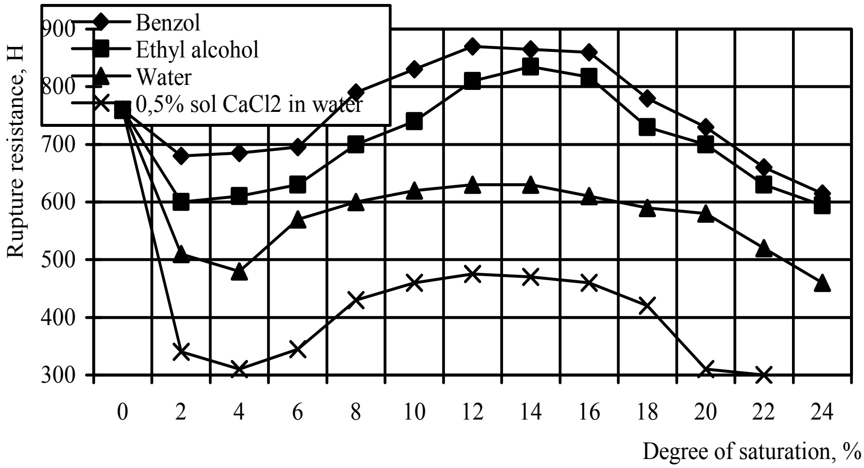

Fig. 1. Dependence of rupture resistance of cement sandish matrix of concrete on degree of saturation by different liquids

As it can be seen on fig.1, all the curve lines have two extremum: minimum at the humidity of the solution 2...4 % and maximum at the humidity of the solution 12...14 %. For the concretes under research the investigating relations are qualitatively analogic. The analysis of the results of the experiments has shown that in first case the humidity of the samples has been changing within the limits of ascending part of the curve from minimum to maximum (see fig. 1), and in the second case it was on descending part of the curve, after the maximum.

The presence of the extremum on the curve lines can be explained by the different force of capillary squeeze of the sample. Thus, at the law saturation (within the limits 0...3 %) the capillary squeeze of the samples is not considerable, the resistibility is lowed because of manifestation of adsorption effect. At the increase of the degree of saturation of the concrete is enlarged the quantity of the pores taking part in the capillary squeeze. The reinforcing effect of capillary forces compensates the adsorption effect of the decrease of resistibility, and, in some cases, leads to the elevation of load-carrying ability of the sample, exceeding it. With the further increase of the degree of saturation, the large pores are filled with the liquid, and the capillary squeeze is decreased (descending part of curve lines). At full saturation of the samples and their research in the state when they are in the liquid, the capillary forces are equal to zero. The decrease of resistibility of concrete in this case corresponds to the full adsorption effect of resistibility decrease [Shchukina 1988, Vagner 1980]. It is important to note that its index is growing only on the first part of the curved line that is at the increase of saturation from the zero to some not large value which, apparently, is corresponding to maximal hygroscopic moisture capacity or to the volume of micro pores. Filling by the liquid of larger pores does not increase the achieved effect of adsorption decrease of resistibility because it is enough water filling in micro pores for its full manifestation.

In carried out experiments it was revealed the influence of polarity of liquids. The resistibility of the samples at its saturation by nonpolar benzol decreased on 10 %, at saturation by water – on 40 %, and at saturation by more polar 0,5 % water solution of $CaC\ell_2$ – on 50 %. Analogic results are obtained at the impregnation of cementing matrix of concrete (Table 1).

Table 1. **Bending resistance R_{bend} and coefficients of softening C_{soft} of cementing matrix of concrete in different media**

Media	R_{bend}, MPa	C_{soft}
Air	18,2	1,00
Toluene	17,6	0,97
Water	14,2	0,78
0,5 % water solution $CaC\ell_2$	12,6	0,69

The dependence of the coefficient of softening C_{soft} on the polarity of the liquid proves that one of the main reasons of the decrease of concrete resistance at water saturation is the adsorption effect of relief of micro crack formation.

The results of investigation introduced in [(Akhverdov 1981] showed that at full water saturation the resistibility of concrete is coming down on 20...60 % in dependence on its pore volume. A great meaning has the character of structure of the concrete at this. With the decrease of the grain of large pores the value C_{size} is increased. For the samples moulded under the pressure 40 and 200 MPa, C_{size} was equal accordingly 0,60 and 0,91. The author [Akhverdov 1981] recommends to restrict W/C in thin-walled reinforced-concrete constructions working in the conditions of water saturation. In particular, the value W/C in flow pipes should be so at which the pore volume of cementing stone does not exceed 11%. The formation of fine-pored structure of the concrete is provided by its hardening in humid medium and more over is better in water. It was established by the experiments that the grain of macro pores with the rad more than 1 mcm in cementing matrix of concrete hardening in the air was about 40%, and while hardening in the water it was only 10%.

The favourable conditions of structure formation of concrete of pipes in humid medium provide more intensive growth of its resistibility than in the air. As the result, the resistibility of the concrete after its long-term operation in water-cut conditions despite adsorption effect can turn to be higher than during the operation in air dry conditions [Kaprielov, Batrakov, Sheinfeld 1999, Batrakov 1998].

It is necessary to mark that both in non-ramming and in water-pressure constructions not the whole volume of the concrete is saturated with water. Its humidity varies in wide limits [Dvorkin, Solomatov, Vyrovoi, Chudnovsky 1999, Kaprielov, Sheinfeld, Silina 2000].

There is not enough data of investigation of the influence of humidity of concrete on its resistibility directly in construction for the establishment of process regularities. The obtained characteristic curves prove the decrease of concrete resistibility nearly 2 times with the increase of its humidity from 2 to 12%. In this case one of the respective reasons of the decrease of resistibility should be the increased pore volume of concrete in more water saturated samples. Because the density of the concrete in water-cut constructions is ranged in rather wide limits, and it can be observed the direct correlation relationship between water saturation and its pore volume, so the dependence of resistibility of concrete on its humidity reflects also the influence of pore volume on its resistibility in latent form. The dependence of resistibility of concretes on its pore volume is enough vivid in general. As it is marked in the work [Alekseev, Ivanov, Modry, Shysl 1990], nearly all famous formulas of resistibility of concrete reflect in different way this dependence.

Thus, it should be taken into consideration that true dependence of resistibility of concrete on its humidity can be obtained only on laboratory samples.

On the ground of the summary of the results of investigation is proposed the linear dependence of resistibility of concrete under the compression and stretch from the humidity:

$$R_W = R_{W_0}\left(1 - \frac{W - W_0}{a}\right), \quad (1)$$

where: R_W и R_{W_0} – the resistibility of concrete at humidity according to the weight equal to W и W_0 accordingly;

a – empirical coefficient depending on the composition of concrete and its structural characteristics.

The dependence (1) is true for the samples of concrete hardening in constant humid conditions during of which the humidity W_0 had been established in the concrete. It is supposed that in distinction from it the humidity W henceforth is established in concrete for the relatively short term directly before the research of the samples so the change of humidity practically does not manage to influence the kinetics of natural strength generation of concrete.

Irregular distribution of humidity on the section of concrete element influences its resistibility. [Sheinich, Popruga 2007, Troshchenko 2005]. The concrete removed from the water during the first time has large additional internal stress caused, on one side, by capillary squeeze of internal zone of section by external layer which gets additional intensity of tension, on the other side, while drying-out of gel constituent, fixed distribution of internal stress in crystal aggregation is disturbed. In such transitional humid regime the resistibility of concrete is usually coming down because of the deformation of the character of the work of different elements of the section.

While stabilizing humid state of the concrete, the irregularity of stress in it is flatten. In the work [Gusev 1989] are given the values of the duration of air keeping of the samples of the concrete of different sizes removed from the water, after which «internal stresses disappear». In reality the internal stresses in cementing matrix of the concrete are always present, but the irregularity of their distribution is coming down [Rudenko 2010, Punagin 2010, Pilipenko 2010].

In fulfilled experiments the relaxation of shrink stress is fixed with the help of magneto-elastic stress gauges. The gauges have been put inside of the samples of fine-aggregate concrete with the size $10 \times 10 \times 40$ cm at concrete pairing. In the samples of modified concrete the gauges did not register considerable changes of stress. While hardening the samples of usual concrete the gauges registered shrink deformations and stresses (fig. 2). During the first 2...3 days when it was observed maximal intensity of shrink deformations, the shrink stresses in internal zone of the samples were not considerable because of the plasticity of the concrete. Further on the stresses have grown violently and at the same time the deformations damped. On the 12^{th}...16^{th} day the growth of stresses stopped and then started their slow reduction. At practically stabilised deformation the shrink stresses have reduced on 30^{th} …40^{th} day to 30…40% of achieved maximal values having left the trace in the structure of the concrete in the way of ruptures of the most strained connections in crystal aggregation.

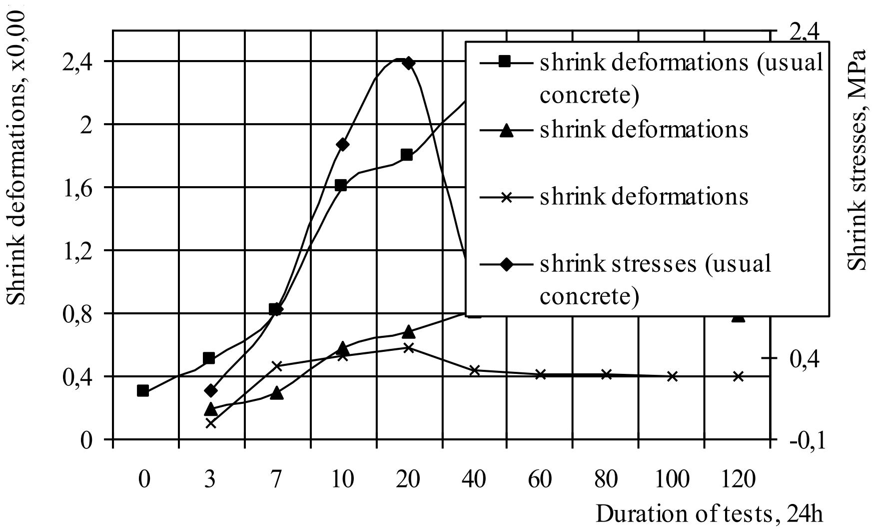

Fig. 2. Change of shrink deformations and stresses in concrete hardening in the air

There did not appear any additional internal stresses in the samples of modified concrete. After removal the samples from the water the indicator of the device immediately started to move showing the growing compressive stress in internal zone of the concrete. This stress, without any doubt, has capillary nature: being immersed in water it disappeared and the indicator came back to zero.

In the experiments the samples made of fine-aggregate concrete have been kept within several months in the air and then they have been tested for the bend after different terms of keeping the samples under water pressure (from 1 to 67 days).

If to ignore the acceleration of the growth of resistibility of the samples during their water saturation, then analysing the results of the tests, it can be done the conclusion of the tendency of modified concrete to restore temporary decreased resistibility in the process of a long-term water saturation.

The degree of decrease of resistibility of the concrete during the first 24 hours of its water saturation depends on the per cent of its loss of humidity during the preceding period of hardening in the air. Under the action of shrink stresses developing during the expulsion of bound water out of the concrete, the definite quantity of internal connections is torn, and it is more, the higher shrink stresses are. [Shchukina 1988, Kruglitskiy 1988].

There are two mutually contrary processes during the water saturation of the concrete: the decrease of resistibility because of adsorption effect and increase of resistibility thanks the decrease of irregularity of distribution of internal stresses caused by shrinkage properties. Besides this, at a long-term water saturation are intensified the processes of the growth of new-growths, partially compensating the relief of cementing matrix. [Pilipenko 2011]. As the result is the achievement of resetting of resistibility of water saturated concrete at a definite complex of conditions of the experiment.

At a periodic humification-torrefaction the resistibility of the concrete is gradually coming down because of repetitive changes in distribution of internal stresses, when each time is accompanied by the destruction of a definite number of connections.

There have been carried out the experiments of the influence of the change of the media on the resistibility of concrete of pipes at the axial tension. The samples-cylinders with the diameter 100 mm and the length 760 mm have been kept in the water during 3 months from the first day of production till the moment of the trial. The part of the samples removed from the water from the testing machine and tore in the air within 30 minutes. The other part of twins-samples has been tested in rubber boots filled with water. The results of the tests are introduced in table 2.

Table 2. **Resistibility of concrete of water storage at strain**

Quantity of cement, kg / m^3	**Resistibility of concrete, MPa, during test at strain**		**Change of resistibility of concrete, tested in the air, %**
	in water	**in the air**	
250	2,13	1,44	– 32,39
300	2,25	2,06	– 8,44
350	2,57	2,90	+ 12,84

The obtained results cannot be explained without taking into consideration the influence of irregularity of distribution of internal stresses in the section of the sample. The decrease of rupture stress at removing the samples out of the water into the air cannot be on the account of the capillary squeeze of the sample in radial directions.

Though the force from the squeeze multiplied by the coefficient of transformation is composed with external force of tension, but more capillary force presses the sample with end bays. The action of all-round capillary squeeze manifested in this case only in the enlargement of irregularity of distribution of stresses in section of the sample. Whereas the concrete of all the samples was fully saturated with water, the adsorption decrease of its resistibility was equal. Breaking of the fixed distribution of internal stresses because of the appearance of capillary forces at the removal of the concrete out of the water led to the decrease of rupture stress.

The samples of cementing stone of water storage sustained in the air different time. The maximal decrease of resistibility was observed after 24 hours of predrying. During further keeping in the air the resistibility of the samples had been gradually restored. The decrease of resistibility is explained by the appearance of shrink stresses, and restoration – by their disappearance. Such explanation is only partially near to reality and it demands the correction taking into account the influence of irregularity of distribution of internal stresses in section of the sample.

With the aim to investigate the influence of humid regime on concrete have been carried out the experiments on bars with the size $2 \times 3 \times 25$ cm of modified cementing sandish solution. The small thickness of the samples besides large filler had been chosen with the purpose of achievement of quick distribution of humidity in section and its stabilization. The experiments showed that both at drying water saturated samples and and water saturation of dried samples i.e. during the first hours of change of humid regime takes place the decrease of resistibility of usual cementing sandish solution. Further storage in the same media (in first case is drying, in the second one is water saturation) leads to the restoration of resistibility. During the test of the samples out of modified cementing sandish solution was no considerable decrease of resistibility at the change of humid regime.

With the enlargement of the thickness of the samples the time of stabilization of their humidity is considerably coming down and at generally accepted sizes of section of samples lasts many months. It is possible that according to this reason, as the result of short investigations was marked only the decrease of resistibility at water saturation of dried samples. On the other side, in experiments with modified concrete was not observed adsorption effect of decrease of resistibility.

In fulfilled experiments had been manifested one of many sides of complex aggregate of phenomena taking place in concrete at change of its humidity – the increase of the coefficient of softening in the process of long water saturation and stabilization of humidity in its section which, possibly, is real. Obviously the increase of the coefficient of softening at long water saturation of modified concrete should be taken into consideration in calculations, and in this connection the stock of reliability will be increased somehow.

The results of investigations of dependence of resistibility of water saturated modified concrete at squeeze on the speed of its load showed that at relatively low speed of load the resistibility of water saturated samples is lower the speed of dried samples as in the definite measure is manifested the effect of adsorption decrease of resistibility. After exceeding some critical speed of load, the humidity does not manage to penetrate into micro crack formation and adsorption effect disappears. At the same time with the increase of speed an important meaning in water saturated concrete has the effect of dynamic acceptation of load of gel constituent. Thanks to this effect is increased the limit of resistibility of concrete by the way that at the speed of load which is more critical the resistibility of water saturated concrete turns to be higher than the resistibility of dried concrete. The average speed of load in critical point is equal to 207 MP a / c, and the average speed of deformation 0,01 m / (m·c).

There have been carried the investigations of the influence of water saturation of concrete on its resistibility at dynamic loads. There have been tested on squeeze the prisms with the size $10 \times 10 \times 30$ cm out of the concrete of the class B 40 at σ_{max} = 14 MPa. The cubes with the size $10 \times 10 \times 10$ cm out of the concrete of the same composition have been tested for the static load. After a long storage of the samples in the air, there was established the humidity 2,3 %. The separated groups of the samples were then saturated with water up to higher values of humidity and were isolated by PVC film. The results are introduced in table 3.

Table 3. **Resistibility and hardness of concrete of different humidity**

Humidity of concrete, %	**Static tests of blocks**		**Dynamic tests of wedges – the quantity of cycles up to destruction, mio.**
	R_{sq}, MPa	**C_{size}**	
2,3	57,2	1,00	More 6
3,3	52,7	0,91	3,72
4,3	50,0	0,86	2,09
5,8	40,6	0,70	0,80

Thus it was defined with the help of experiments that for the operation conditions, the humidity of concrete should not exceed 4%, taking into consideration the conditions of work for its endurance (2 mio of cycles of load).

In many experiments according to the definition of resistibility of concrete the large-scale effect manifests vividly that in some cases cannot be discovered at all. The nature of this effect is not finally clear. At present the most accepted is the static theory of large-scale effect which essence is in increase of probability of transfer dangerous defects of structure of material in section of the sample with the increase of its sizes. The analysis of wide experimental material shows that besides of probable factor of large-scale effect act simultaneously the others. They are sometimes determinant.

It was established by carried investigations of manifestation of large-scale effect in concretes that the last one is caused not by the sizes of the sample but their function – the degree of non-uniformity of the structure of concrete.

On the ground of mathematic processing of results of specially planned of experiments was obtained empiric formula of large-scale coefficient for the samples of modified concrete:

$$К_{м} = \frac{1}{5C_{\upsilon}^{2}\left(\frac{1}{M} - 1{,}67\right) + 1}, \qquad (2)$$

where: C_{υ} – coefficient of variation of resistibility of concrete;

$M = S / V$ – module of surface – dependence of surface of the sample to its volume.

Developing this thought, it can be done the conclusion that the large-scale effect is the consequence of non-uniformity of distribution of stresses in section. With increase of non-uniformity, the resistibility of the material is coming down not depending on the sizes of the sample. The sizes make indirect influence: with the increase of the sizes of the sample in many cases the non-uniformity of stresses in section increases, and the decrease of resistibility of concrete takes place, but it is not always. Thus, for example, as the result of carried experiments it was established that the resistibility of modified concrete at axial squeeze and strain does not depend on the sizes of cross section of the sample on condition that in all samples the humidity is equal and is regularly distributed in section. From this point of view the analysis of foreign literature is very interesting [Smadi, Mohammad, Slate, Floyd 1989, Neely, Billy, Saucier, Kenneth 1990]. From the published materials follows that the resistibility of the concrete drilled out of solid monolith does not depend on the diameter of the kern. It can be explained only by equal law of distribution of internal stresses in kerns of al sizes as it is predetermined by equal conditions of structure formation and humidity distribution in all the volume of internal zone of concrete monolith.

Thus, the results of carried out experiments allow to define the ways of decrease of irregularity of distribution of internal stresses in cementing matrix of modified concrete. The main way of decrease of irregularity of distribution of internal stresses is likely to be the destruction of the most stressful connections at the early stages of concrete hardening in order that instead of them there have been formed new connections of the same material with initial stress coming close to average value for the whole crystal aggregation. The destructions of the most stressful connections to some degree is achieved at vibro impactive poly-roll of concrete mixture.

The increase of the resistibility of concrete in the result of physical modification of concrete mixture should be partially referred for the removal of aggregations of sediment water under the grains of huge filler. The increase of resistibility of concrete as the result of vibro activation is explained by the increase of structural uniformity by destruction of primary weak aggregations and on their place formation of fine-pored structure of cementing matrix with regular distribution of internal stresses.

CONCLUSIONS

1. It was established that early loading of modified concrete leads to the increase of its resistibility on 30 %. It is evidently also connected with the destruction of overstrained connections and new connections formation with a low internal stress.

2. One of the directions of the achievement of project operating abilities of concrete can be active physical chemical influence on the process of structure formation of cementing matrix of concrete and the development of ways of the increase of uniformity of distribution of internal stresses in it.

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ВЛИЯНИЕ ВОДОНАСЫЩЕНИЯ БЕТОНА ТРУБ НА ИХ ПРОЧНОСТЬ

Владимир Пилипенко

Аннотация. В статье представлены результаты исследований влияния неравномерного водонасыщения на эксплуатационные характеристики модифицированного бетона специального назначения. Установлены зависимости прочности бетона от степени насыщения жидкостями различной полярности, в том числе водой. Показано, что одним из направлений достижения проектных эксплуатационных свойств бетона может быть активное физико-химическое воздействие на процесс структурообразования цементной матрицы бетона и разработка способов повышения однородности распределения внутренних напряжений в нём.

Ключевые слова: модифицированный бетон, водонасыщение, прочность, коэффициент размягчения.