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MECHANICAL PROPERTIES OF POROUS CONCRETE DURING COMPRESSION

Abstract. Results of the experimental studies of the force resistance and deformation of compressed elements from porous concrete of 1200-1600 kg/m^3 density of various structural modifications (fine grain and micro grain) are presented. On the basis of research date, mechanical properties are complexly characterized; a criterion number of strength and deformation characteristics of porous concretes with due regard for the influence of long-time processes due to concrete hardening and external force factors is proposed. On the basis of data on the long-term resistance of porous concrete and change in its strength in time, calculation characteristics and coefficients of operation conditions of porous concrete are established for calculation and design of structures. It is shown that according to structural indicators, porous concretes meet normative requirements and occupy the intermediate place between cellular and light concretes of equal strength with porous fillers.

Keywords: porous concrete, mechanical properties, measure of creep, long-term strength, force resistance.

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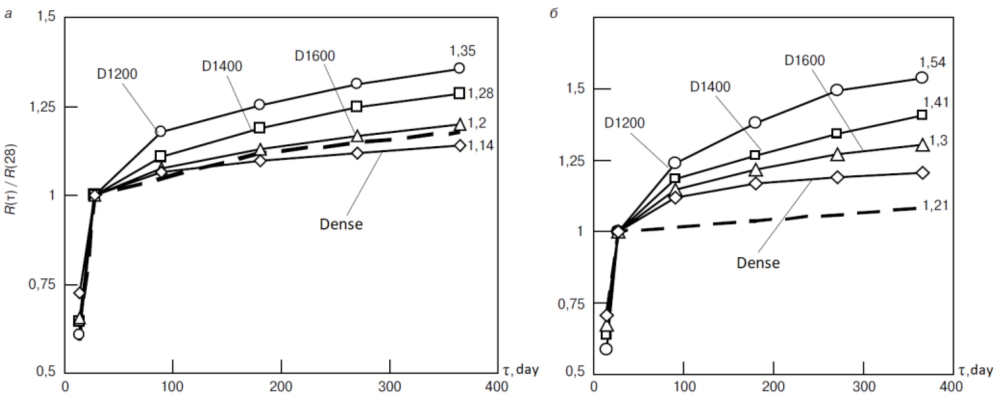
Introduction. In the practice of modern housing and civil construction area of application of light macroporous new generation of lightweight concrete (foam-, gas- and porous- bathtubs of natural hardening concrete) constantly is expanding [1-7]. At the same time, deformation-resistant the properties of these types of concrete have been studied we are currently still not enough, and the estimated characteristics necessary for the design of electrical structures, do not have sufficiently complete design bases. This makes it impossible in some cases their use instead of traditional materials, and in generally limits the scope of application of new different types of concrete for load-bearing structures. In connection with these aspects, commercial comprehensive studies of physical and mechanical properties porous concrete for short-term and long-term load under conditions of central compression Tia. As a result of the implementation of these studies, information that allowed the assessment to be made structural potential of porous concrete natural hardening and establish experimental but statistical dependencies between mechanical properties of porous concrete of various modifications cation and its average density. Mechanical and rheological study program properties of porous concrete under compression included short-term and long-term testing of samples prismatic shape with dimensions 100×100×400 and 150×150×600 mm and cubes with ribs 100 and 150 mm long. The samples were prepared from cement fine- and micro-grain low porous concrete grades according to medium density features D1200, D1400, D1600. Dense concrete is considered was used as a matrix material for the corresponding existing types of porous concrete.

Conditions and methods of research. The raw materials for the samples were: Portland cement grade PS500 D0 JSC "Oskolcement"; superficial active substance (surfactant) air-entraining action "Penostrom"; quartz sand size M_k=1.4 Tambov quarry, Voronezh region and fly ash with S_{ud} = 300 m^2/kg and K_{osn} = -0.151 (according to P.I. Bozhe-new) Voronezh CHPP-2 for fine and micro-grain hundred concrete respectively. Porous concrete the mixture was prepared by one-stage stirring in for 4 minutes at a speed of 15 s^{-1} in a turbine-mixer the type. Required average density of concrete mixture was achieved by changing the dosage of air entrainment additives in the range of 0.05–0.1% by weight of cement at 10% concentration of its working solution.

Short-term testing of concrete samples were carried out on a PMS-20 type press in equal stepsmi loading according to the standard method. Registration longitudinal and transverse deformations were carried out electrical strain gauge method and using indial indicators with scale divisions 0.001 mm. To study structural changes porous concrete during loading, conditional by the appearance and development (Figures 1,2).



a – fine-grained concrete; b – micro-grained concrete; porous concrete, hardened in laboratory conditions; porous concrete D1200, hardened under natural conditions.

Figure 1. The rate of increase in the relative strength of porous concrete over time

The time it took for ultrasound to pass through the sample was measured. At all stages of experimental data analysis statistical methods were used to assess the reliability of the experimental results.

The long-term testing methodology was developed in accordance with GOST 24544–81 and recommendations of NIIZHB. The samples were loaded with a long-term load at the age of 28–30 days. lever type installations. Loading mode is stepwise, 0.05–0.1 Rb each with four-minute exposures at every step. The value of long-acting load was different and ranged from 15 to 95% of destructive short-term.

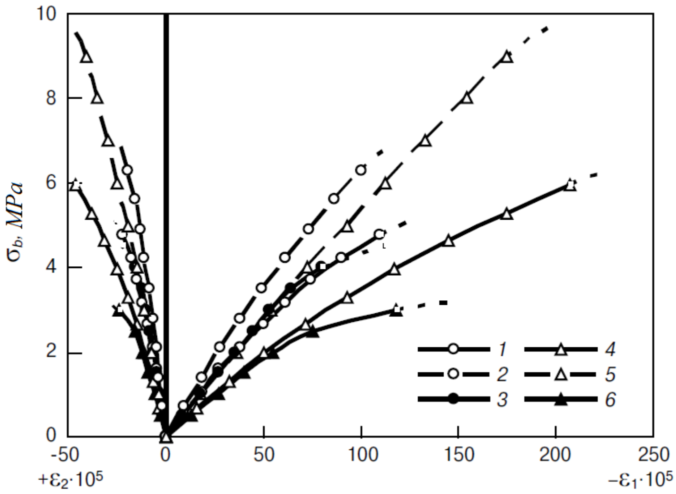


Figure 2. Diagram of compressive strains of porous concrete grade D1200; 1,2,3 – fine-grained concrete, respectively aged 28 days, 1 year and 15 years; 4,5,6 – the same, micro-grained of compression microcracks.

Table 1

Characteristics of concrete

Properties	Type of dependencies	
	Fine concrete	Fine-grained concrete
Cubic strength, MPa	$R=3.3 \cdot p^{-3.5}$	$R=3.2 \cdot p^{-4}$
Prismatic strength, MPa	$R_b=3 \cdot p^{-3.4}$	$R_b=3.3 \cdot p^{-3.6}$
Initial modulus of elasticity, MPa	$E_b=3.7 \cdot p^{-2.7} \cdot 10^3$	$E_b=2.5 \cdot p^{-2.8} \cdot 10^3$
Ultimate compressibility	$\varepsilon_{bu}=(-p^{-2}+4p-2) \cdot 10^{-3}$	$\varepsilon_{bu}=(-2.5p^{-2}+9p-5) \cdot 10^{-3}$
Note: $p=p/p_0$ – relative average density of concrete at the accepted value $p_0=1$ t/m^3, so $p=p$ it is dimonsionless; coefficient in the equations are the initial values of the corresponding characteristics.		

Each batch of samples intended for long-term load testing consisted of three groups of prisms. The first group was subjected to short-term tests in the press to determine the destructive loads; the second group was loaded with a long-term constant load of different levels to determine the total creep and shrinkage strains; the third group of samples was kept without load for measurements of temperature-shrinkage strains, which were subtracted from the strains of the loaded samples. To prevent moisture exchange with the environment samples of the last groups after 28 days of normal hardenings were isolated with paraffin and two layers of polyethylene film. Individual batches of samples served to identify trends in the growth of short-term strength and elastic modulus over time during concrete hardening.

Research results. Registration of deformations was carried out by dial indicators mounted on the side faces prisms with a base of 200 mm. Duration of long creep tests lasted 200 days, after which the experimental elements were unloaded and onto them within. Elastic aftereffect deformations were measured for 70 days. At the same time, at the age of concrete at which the samples were unloaded, to check one of sides of the principle of superimposition of influences, for the first time twin samples were loaded with the same constants voltages of various levels.

After completion of creep testing of samples and shrinkage, their short-term strength and elastic modulus were determined in order to evaluate the measure changes in these characteristics under the influence of long-term constant load of the specified levels.

The experiments were carried out in the laboratory at temperature T=(20±2)°C and relative air humidity φ=(80±5)%.

Influence of average density and type of structure on mechanical properties of porous concrete can be follow the experimental-statistical dependencies presented in Table 1. Comparison of exponents in these dependencies allows us to assert that as the changes in the average density of concrete increase strength and elastic modulus of micrograins low concrete is more significant than for fine-grained concrete Strength of micro-grained concrete at a similar average density is 10–20% higher, and the elastic modulus guests, on the contrary, are 25–35% lower than fine-grained concrete. Coefficient prismatic strength of fine-grained concrete averages 0.87, micro-granular – 0.91.

All studied concrete modifications had an elastic-plastic nature of deformation during compression. Transition boundary work of the material into the plastic stage was at the stress level corresponding to (0.3–0.5)Rb for fine-grained concrete and (0.25–0.35)Rb for micro-grained concrete. Coefficient of ductility to moment destruction of micro-grained samples 20-30% more concrete than fine-grained concrete. Ultimate compressibility 1.5–2 times more for micro-grained concrete than that of fine-grained concrete. Transverse strains during compression in 4–6 times less than longitudinal ones. Coefficient The Poisson ratio for porous concrete was 0.21±0.2. To approximate the compression strains, we used the dependence type:

$$\varepsilon_b = A \cdot \ln\left(1 - \frac{\sigma_b}{\varsigma \cdot R_b}\right), \tag{1}$$

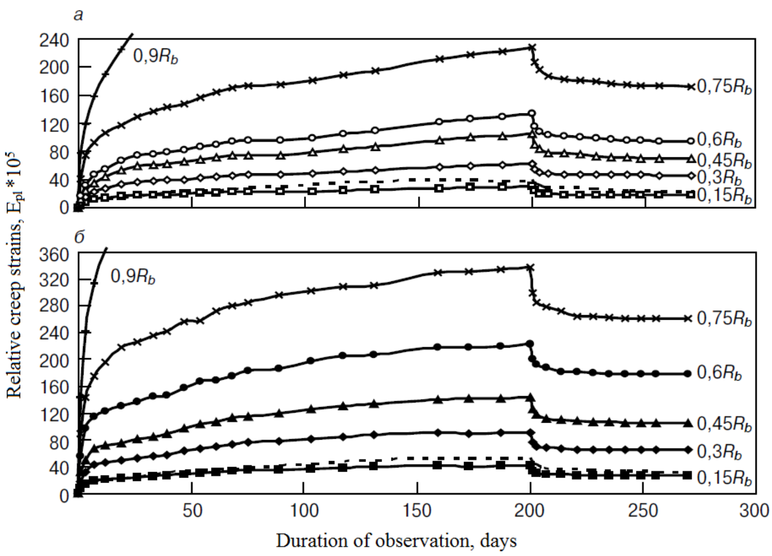
where *A* is parameter determined from experience.

Crack formation in concrete elements cops occurred, as a rule, during dis-crushing load or load close to destructive. The upper limit is not tim microfractures R^{v}_{crc} crc was in within a wide range (0.68-1) from the prismatic concrete strength R_b. Results of statistical analysis allowed us to conclude that the distributions of the limits strength and elastic moduli of the studied compounds of porous concrete obey normal law. In all cases, the ratio of asymmetry and the amount of time to make your mistakes was less than three, which is evidence spoke about the random nature of the errors themselves and their unreliability. Hypothesis testing is normal distribution of R_{bm} and E_{bm} values, carried out according to χ^2-criterion and Kolmogorov – Smirnov criterion, confirmed the results of the rough check and accepted at the 10% level. Based on the results of processing ex-experimental data using variational statistical methods statistics were obtained, normative and calculated the values of the tensile strength and elastic modulus and the corresponding reliability coefficients were calculated according to the material (Table 2). When hardening porous concrete for a year in the unloaded state a stable increase in strength and elastic modulus (Fig. 3).

Table 2

Name of characteristics	Type of structure and brand by average concrete density						Regulatory data			
	Fine-grained			Micro-grained			Lightweight co		Cellular concrete	
	D1200	D1400	D1600	D1200	D1400	D1600	Dense	Porous	Autocla - ved	Non-autoclaved
Concrete class by compressive strength	B5	B10	B15	B7,5	B12,5	B20	B5–B15			
Standard Rb,n and calculated resistance for limit states of the second group Rb,ser, MPa	4,4	9	13,3	5,2	9,9	16,4	3,5–11		4,6–11,5	
Design resistance for limit states first group R_b, MPa	3,7	7,9	11,9	4,3	8,1	14,7	2,8–8,5		3,1–7,7	
Material reliability coefficient for strength γ_b	1,20	1,15	1,12	1,2	1,23	1,11	1,3		1,5	
Initial modulus of elasticity in compression $E_b \cdot 10^{-3}$, MPa	3,9	6,5	10,3	2,8	4,4	6,6	5–14		4–9,3	3,2–7,4
Initial modulus of deformation for a long time load action $E_{b,\tau} \cdot 10^{-3}$, MPa	1,2	2,4	3,9	1,2	2,2	3	2,1–5,2		1,7–2,5	1,2–1,7
Poisson's ratio $\nu_{b,p}$	0,18	0,18	0,2	0,21	0,23	0,24	0,2			
Limit relative deformation under continuous load $E_{b0} * 10^3$	1,3	1,4	1,8	2,3	2,6	3	–	–	–	–
Standard value of the creep measure $C_{b,\tau}* \cdot 10^5$, MPa^{-1}	61,9	31,5	18	61,6	34,2	21,6	27–12		64–30	87–44
Creep characteristic $\varphi_{b,cr}$	3,6	3,2	2,4	2,5	2,2	1,9	1,4–1,7		1,4–2,8	1,5–3,3
Operating condition coefficient γ_{b1}	0,9	0,85		0,9		0,85	1; 0,9	0,85	0,85	0,85
Coefficient β in formula (21) SNiP 2.03.01–84*	1,8	1,6	1,2	1,3	1,1	1	1; 1,5; 2,5	2	1,3	1,5
Creep coefficients in formula (156) SNiP 2.03.01–84* φ_{b1}	0,85		0,9	0,83	0,84	0,85	0,85	0,7	0,85	
Creep coefficients in formula (156) SNiP 2.03.01–84* φ_{b2}	4	3,5	3,1	3,2	3,1	2,8	2			

Note. * SNiP 2.03.01–84 "Concrete and reinforced concrete structures"; SP 63.13330.2012 "Concrete and reinforced concrete structures. Basic provisions"; Updated edition of SNiP 52-01–03; A manual for the design of residential buildings. Vol. 3. Designs of residential buildings (to SNiP 2.08.01–89).



aftereffects of fine-grained (a) and micro-grained (b) porous concrete at different levels of compressive stress: ——— – porous concrete using the example of a grade D1600 loaded at 28 days of age; – – – – – aerated concrete D1200, for the first time loaded at the age of 15 years with voltage $\sigma=0.3R_b$

Figure 3. Experimental curves of relative creep and elastic strains

The growth rates of these indicators reached 1.35 and 1.24 respectively for fine-grained concrete and 1.54 and 1.38 for micro-grained concrete [8]. To describe kinetics of their growth during hardening (aging) aerated concrete, acceptable solutions provide dependencies (2) and (3) with corresponding quantitative parameters:

$$R_t(\tau) = \kappa + (R_{28} - \kappa) \cdot 0.69lg\tau \quad (2)$$

$$E(\tau) = E_0[1 - \beta_1 \cdot e^{-\alpha 1\tau} - \beta_2 \cdot e^{-\alpha 2\tau}], \quad (3)$$

where is the age of concrete, days; R_{28} – prismatic strength porous concrete aged 28 days, MPa; E_0 – limiting value of the elastic modulus of concrete, MPa; , and a are parameters determined from experience. During normal hardening of porous concrete, the proportion of plastic deformations decreased, and elastic – increased by an average of 10-15%, which was confirmed by an increase in the slope of the curves on the deformation diagram (Fig. 2). The maximum compressibility during the annual hardening period decreased, and the limit elasticity, on the contrary, increased by an average of 10% for fine-grained porous concrete and by 15% for micro-grained concrete. Poisson's ratio in the process of observation.

The production of concrete has remained virtually unchanged. During the hardening of porous concrete under long-term load, an increase in strength was also noted and modulus of elasticity under axial compression [9]. Hardening mainly occurred under prolonged stress, corresponding to the area of linear creep, and amounted to 15 and 10%, respectively, for fine-grained concrete, up to 20 and 12% for micro-grained and up to 10 and 8% – for dense concrete.

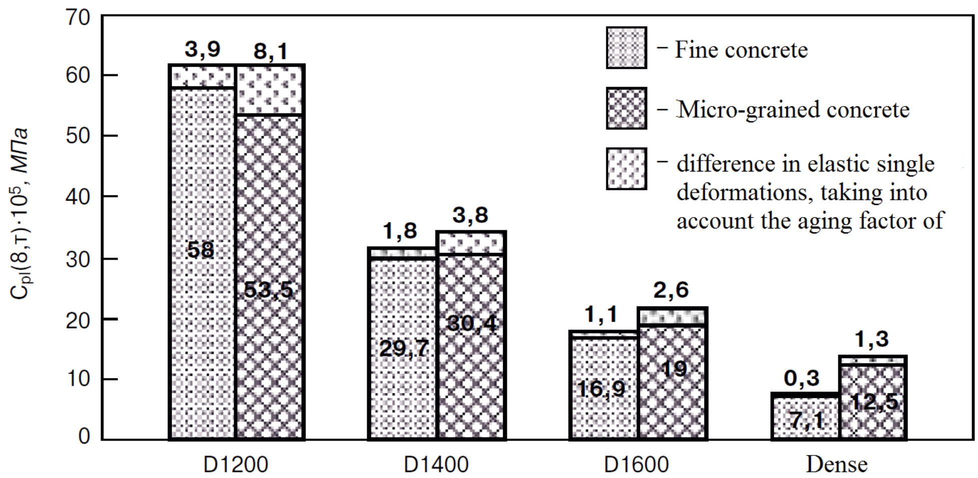


Figure 4. Limit values of the measure of linear creep taking into account the aging of porous elements low and dense concrete

At higher voltages, R_b and E_b decreased, which is apparently due to with the development of microcracks in the concrete structure. Creep tests have shown that the process of deformation of porous concrete under stress compression $\leq 0.75R_b$ sequentially passed through three phases: the phase of unsteady creep – the phase of steady creep, when the strain rate is constant – the phase of decaying creep (Fig. 3). For fine-grained concrete is characterized by lower initial creep rates and later periods of creep stabilization than for fine-grained concrete. It has been established that up to stress levels corresponding to 0.6 R_b for samples made of fine-grained concrete and 0.45 R_b for micro-grained concrete, deformation creep is almost linearly related to stresses, and at higher stresses it is nonlinear (Fig. 4). And only near the moment of loading the samples nonlinearity appeared at lower voltages and completely disappeared after 1.5–2 weeks of exposure to load. It is important to clarify that due to the increase in concrete strength over time since the beginning of the observation, the actual ratio of stresses in the samples to the ultimate strength /R_b decreased and, as a consequence, the transition boundary of the linear region decreased creep into nonlinear [10].

By the end of the experiments, it reached 0.47, 0.49 and 0.52 R_b for fine-grained and 0.32, 0.34 and 0.36 R_b for micro-grained porous concrete grades of average density D1200, D1400 and D1600 respectively.

Essentially, porous concrete does not have increased long-term deformability compared to other types of cellular concrete (Table 2). The characteristic and measure of creep by the time the experiments were completed were in the range of 1.7–3 and (12.8–49.6)·10^5 MPa^{-1}, respectively, for fine-grained concrete and 1.3–2.6 and (15–58)·10^5 MPa^{-1} – for micro-grained concrete. The values of these indicators are greater, the lower the average density of concrete and the higher the level stress. Concretes of dense fine and micro-grained structure were characterized by a measure of creep, equal to 5.8·10^5 and 11.4·10^5 MPa^{-1}, respectively. Rapid creep strains were up to 10–14% creep strain measured at end experience. Limit values of specific deformations creep $C(\infty,\tau)$, identified by regression analysis and adjusted taking into account the aging of concrete, are presented in Figure 5.

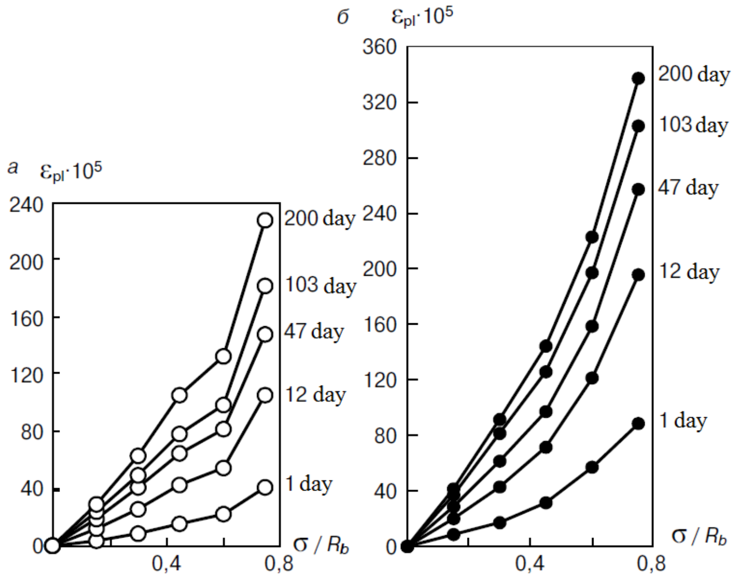


Figure 5. Dependence of relative creep strains of porous concrete D1600 on initial stress levels over time: a – fine-grained concrete; b – micro-grained concrete;

Discussion of scientific results. Analyzing the deformations based on the elastic aftereffect of porous concrete, measured over 70 days, it should be noted that they are damped in time character. We can assume that they are linear depend on the stresses acting in the samples before they were unloading With the same grade of concrete on average the deformation density of the aftereffect of micro-grained concrete is greater than that of fine-grained concrete, on average by 10–30%, and the measures of their aftereffect are equal or, conversely, less by 10%. The reduction in the elastic aftereffect with increasing average density for micro-grained concrete was less significant, than for fine-grained concrete.

Checking the degree of reversibility of creep deformations of porous concrete revealed the presence of irreversible deformations not associated with the aging of concrete, and caused, apparently, by a violation of its structures under long-term load. In the region of linear creep, its share is on average 0.56 and 0.47 respectively for fine- and micro-grained concrete. In connection with this circumstance, the principle of superimposing influences to identify deformations of porous concrete during complete unloading can lead to some errors. For the theoretical interpretation of creep and elastic aftereffect curves of porous concrete

The most acceptable models of the hereditary theory of aging, proposed by S.V. Aleksandrovsky [11] and V.M. Bondarenko [12, 13].

The long-term strength of porous concrete was determined in two ways. The first method is based on direct experimental study long-term strength and extrapolation of the obtained logarithmic dependence data to the desired moment in time. Here, the samples taken for research were loaded with a long-term compressive load high level with an interval of $0.05R_{bm}$ at each level. The second method allowed us to approach the assessment limit of long-term strength of concrete from the standpoint of fracture mechanics according to work (4) [14]:

$$\eta(t,\tau)=\frac{R_{bl}(t,\tau)}{R_b(\tau)}=\frac{m(t,\tau)R_b(t)}{R_b(\tau)}\sqrt{\frac{E_b(\tau)}{E_b(t)}\left(\frac{1}{1+E_b(\tau)\cdot C(t,\tau)}\right)}, \tag{4}$$

where $R_{bl}(t.\tau)$ is the long-term resistance of concrete to axial compression; $R_b(\tau)$ $E_b(\tau)$ – respectively prismatic strength and modulus of elasticity of concrete at the moment of application long-term load; $R_b(t)$ $E_b(t)$ – the same, at the moment of termination of the long-term load, when the properties concrete are stabilized; $C(t.\tau)$ – specific deformations creep of concrete; $m(t.\tau)=R_b(t)/R_b(t)$ – ratio the temporary strength of concrete taking into account the previous long-term loading to the short-term strength of concrete loaded for the first time.

As a result, the long-term strength coefficient during compression was taken equal to 0.66 and 0.69, respectively, for fine- and micro-grained porous concrete. The values of the characteristics of porous concrete recommended for the calculation and design of structures, taking into account the influence of long-term processes caused by aging and creep of concrete, are presented in table 2. Standard values are also given here measures and characteristics of creep of the concrete under study, which can be used to determine calculated creep characteristics taking into account real conditions in which the structure operates.

Conclusion. Based on experimental and theoretical studies, standardized physical and mechanical characteristics of porous concrete of different sizes have been established. personal modifications taking into account their variability, the aging of concrete and the duration of the load. They can be used for calculation and design structures made of porous concrete and thereby promote a wider introduction of porous concrete into construction practice [15]. Wherein fine-grained porous concrete is more preferable for practical use, since the same average density and insignificant the difference in the measures of creep, its shrinkage deformation by 40% less than micro-grained concrete.

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СЫҒЫЛҒАН КЕЗДЕГІ КЕУЕКТІ БЕТОННЫҢ МЕХАНИКАЛЫҚ ҚАСИЕТТЕРІ

Аңдатпа. Орташа тығыздығы 1200-1600 кг/м^3 әртүрлі құрылымдық модификациядағы (ұсақ түйіршікті және микротүйіршікті) кеуекті бетоннан жасалған сығылған элементтердің күшке төзімділігі мен деформациясының тәжірибелік зерттеулерінің нәтижелері берілген. Зерттеу деректері негізінде механикалық қасиеттері жан-жақты сипатталды және бетонның қатаюынан және сыртқы күш факторларынан туындаған ұзақ мерзімді процестердің әсерін ескере отырып, кеуекті бетонның беріктігі мен деформациялық сипаттамаларының критикалық қатары ұсынылды. Кеуекті бетонның ұзақ мерзімді кедергісі және оның беріктігінің уақыт бойынша өзгеруі туралы мәліметтер негізінде конструкцияларды есептеу және жобалау үшін кеуекті бетонның жұмыс жағдайларының есептік сипаттамалары мен коэффициенттері белгіленеді. Құрылымдық көрсеткіштері бойынша кеуекті бетондар нормативтік талаптарды қанағаттандырады және кеуекті толтырғыштардағы бірдей беріктіктегі ұяшықты және жеңіл бетондар арасында аралық орынды алады.

Тірек сөздер: кеуекті бетон, механикалық қасиеттері, сусымалы өлшем, ұзақ мерзімді беріктік, күшке төзімділік.

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МЕХАНИЧЕСКИЕ СВОЙСТВА ПОРОВОГО БЕТОНА ПРИ СЖАТИИ

Аннотация. Представлены результаты экспериментальных исследований силового сопротивления и деформирования сжатых элементов из поризованного бетона средней плотности 1200-1600 кг/м^3 различных структурных модификаций (мелкозернистый и микрозернистый). По данным исследований комплексно охарактеризованы механические свойства, предложен критериальный ряд прочностных и деформативных характеристик поризованных бетонов с учетом влияния длительных процессов, обусловленных твердением бетона и внешними силовыми факторами. На основании данных длительного сопротивления поризованного бетона и изменения его прочности во времени для расчета и проектирования конструкций установлены расчетные характеристики и коэффициенты условий работы поризованного бетона. Показано, что по конструкционным показателям поризованные бетоны удовлетворяют нормативным требованиям и занимают промежуточное место между равнопрочными ячеистыми и легкими бетонами на пористых заполнителях.

Ключевые слова: поризованный бетон, механические свойства, мера ползучести, длительная прочность, силовое сопротивление.