DETERMINATION OF THE BOUNDARY OF THE LINEAR CREEP OF EXPANDED CLAY CONCRETE DURING COMPRESSION

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Abstract. *The paper presents the results of experimental data on creep and shrinkage, and the kinetics of the change in the creep measure of expanded clay concrete over time under axial compression at different levels of long-term load (0.2 – 0.7)Rb. Empirical formulas convenient for practical application for determining creep deformation and shrinkage of expanded clay concrete are proposed.*

Keywords: *expanded clay concrete, strength, modulus of elasticity, long-term load, creep, shrinkage, creep measure.*

ОПРЕДЕЛЕНИЕ ГРАНИЦЫ ЛИНЕЙНОЙ ПОЛЗУЧЕСТИ КЕРАМЗИТОБЕТОНА ПРИ СЖАТИИ

Аннотация. *В работе представлены результаты экспериментальных данных по ползучести и усадке, а также кинетика изменения меры ползучести керамзитобетона во времени при осевом сжатии при различных уровнях длительной нагрузки (0,2–0,7)Rb. Предложены удобные для практического применения эмпирические формулы для определения деформации ползучести и усадки керамзитобетона.*

Ключевые слова: *керамзитобетон, прочность, модуль упругости, длительная нагрузка, ползучесть, усадка, мера ползучести.*

INTRODUCTION

Rational design of prestressed structures made of expanded clay concrete can be ensured only if such important characteristics as shrinkage and creep during compression are properly taken into account [1-4].

In the operating conditions of the structure, when concrete is constantly subjected to alternating moistening and drying, the creep deformation increases, i.e. the results of laboratory tests do not allow to accurately determine the real creep deformation value is noted in [5, 6]. A higher temperature leads to an increase in the initial creep rate compared to concrete tested at normal (room) temperature. The creep deformations of concrete are very significant and should always be taken into account in addition to the initial elastic deformations.

MATERIALS AND METHODS

The composition of expanded clay concrete is given in Tables 1 and 2. As a large aggregate, expanded clay gravel of the Tashkent plant of two fractions: 5-10 and 10-20 mm in a ratio of 40:60. The cement of the Navoi cement Plant was used as Portland cement, and the sand of the Tashkent quarry was used as quartz sand.

Table 1

Composition of expanded clay concrete (CC)

Actual consumption of materials per m^3 of concrete	cement, kg	427
	sand, kg	629
	expanded clay, kg (l)	414(727)
W/C (water/cement ratio)		0,49

Table 2

Characteristics of expanded clay concrete

Bulk density of dry expanded clay concrete, kg/m^3	1760
Cubic strength, R, MPa	33.0
Prism strength, R_b, MPa	28.4
Prism strength factor, R_b/R	0.86
Initial modulus of elasticity, E_b, Pa	15.4

Note: Specimens were tested at the age of 28 days. Prisms dimensions - 150x150x600 mm, cubes ribs - 150 mm. The cone slump of concrete mix - 1...2 cm.

Loading of samples at different stress levels was carried out in spring and lever installations with a maximum force of 210 kN, respectively. During testing, the prism samples with a size of 70x70x280 mm were installed with 30 cm thick metal base plates with ball joints glued to the ends. When loading with high load levels, one sample was installed in the installation (Fig. 1, a), and two samples were installed with low load levels (Fig. 1, b).

When installing two prisms, metal plates with a thickness of 20 mm were laid between them.

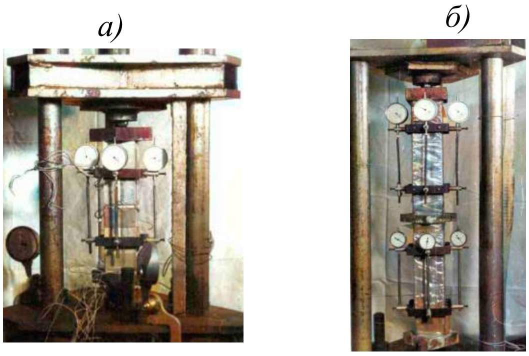

Fig. 1. Testing of samples under prolonged compression

In order to eliminate the error associated with the nonadditivity of shrinkage and creep, the samples were waterproofing on the sides before loading with a layer of paraffin 2-3 mm thick and two layers of polyethylene film with sizing the seams with insulating tape.

Before the samples were loaded with a long-acting load, their twins were tested on a press according to a similar scheme with a short-term load action before destruction. At the same time, the cubes were tested.

The test of samples loaded under load at (0.20 – 0.70)Rb levels lasted for 210 days, and then they were unloaded and the deformation effects were measured for 56 days. After 56 days after unloading, the main and control samples were brought to destruction under the short-term action of the compressive load and the elastic modulus and compressive strength were determined to determine the value of the function $m(t,\tau_1) = R'/R \cong E'/E$ (where $R'/R \cong E'/E$ is the strength and modulus of elasticity, respectively, of the main and control samples), taking into account the influence of the previous loading of the material on the short–term strength and modulus of elasticity.

RESULTS

The kinetics of changes in the creep measure of expanded clay concrete over time during axial compression are shown in Fig. 2, and shrinkage deformations are shown in Fig. 3. The growth curves of the creep measure of the samples have the greatest rise in the initial period after the application of the load (30 days), in the future there is a slight decrease in the growth of the creep measure with a tendency to stabilization. Up to stresses of 0.4Rb, creep deformations of expanded clay concrete under compression develop almost in a conditional linear region. At *0.5Rb*, creep deformations clearly do not develop according to a linear law, it can be assumed that in the case of $\sigma_l/R_b > 0{,}4$, microcracks begin to appear in the samples.

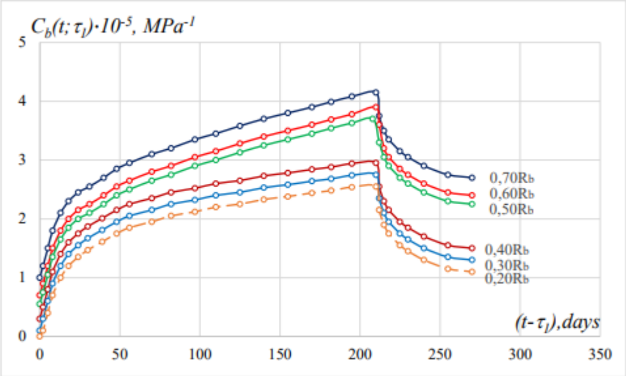

Fig.2. Kinetics of the change in the creep measure of expanded clay concrete in time for axial compression at different levels of long-term load

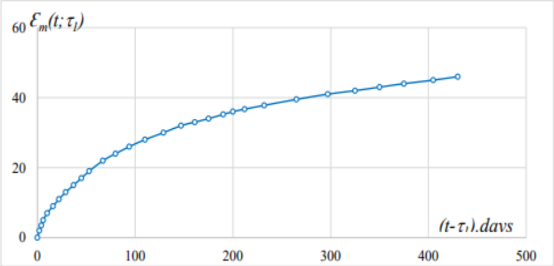

Fig. 3. Kinetics of changes in shrinkage deformation of expanded clay concrete over time

When analyzing the nature of changes in creep deformations, a simpler method was used to identify the nonlinearity of their development. Figure 4 shows the graphical dependences of the creep limit strain $\varepsilon_{x,p}(\infty,\tau_1)$, determined according to GOST 24544-97, on the magnitude of the relative stresses of long-term compression σ/R_b. As follows from this graph, in expanded clay concrete up to stresses of 0.4Rb, creep deformations develop almost in a linear region. The results obtained are in good agreement with the data of [7].

In [7], the dependence is proposed to determine the relative deformation of the nonlinear creep of expanded clay concrete:

$$\varepsilon_{x,p}(t;\tau_1) = (\sigma_{bl} + \alpha\sigma_{bl}^3)C_b(t;\tau_1) \tag{5}$$

where σ_{bl} is the effective voltage in MPa;

α – numerical coefficient determined from experience;

$C_b(t;\tau_1)$ is a measure of the linear creep of expanded clay concrete, which can be determined by the dependence proposed in [13].

For the numerical solution of equation (5), it is necessary to determine the values of the limit of short-term strength under axial compression and tension and the creep measures $C_b(t;\tau_1)$, $C_{bt}(t;\tau_1)$ and its change in time, the values of the elastic modulus and the functions $m(t;\tau_1)$.

The values of the measure of linear creep of the mortar part of expanded clay concrete under axial tension (if there are no direct experimental data) are determined by the formula (6)

$$C_{bt}^*(t;\tau_1) = \lambda(t;\tau_1)C_b(t;\tau_1); \tag{6}$$

Where

$$C_b(t;\tau_1) = \frac{70R_b^2(\tau_1-2)+13000R_b-140000}{(177R_b-1700)R_b\tau_1^{3/2}}10^{-5} \quad + \frac{0,2R_b+15\tau_1-0,2R_b+100}{R_b}\left[1 - e^{-y(t-\tau_1)}\right]10^{-5}; \tag{7}$$

$$\gamma_1 = 0,015 + 18/R_b; \tag{8}$$

the second multiplier in the formula (8) is taken into account when $\tau_1 > 16$ days.

$$\lambda(t;\tau_1) = a + \frac{b(t;\tau_1)}{t_1}. \tag{9}$$

Based on experimental data for expanded clay concrete of dense structure (on quartz sand):

$a = 2.15$; $b = 0.63$ at $0 < (t-\tau_1) \le 2$ days.
$a = 3.40$; $b = -0.077$ at $2 < (t-\tau_1) \le 15$ days.
$a = 2.25$; $b = -0.03$ at $15 < (t-\tau_1) \le 100$ days.
$a = 2.00$; $b = 0$ at $(t-\tau_1) > 100$ days.

The values of the function $m(t;\tau_1)$, taking into account the effect of a prolonged load on the change in the surface energy of the material in the crack zone for expanded clay concrete, are calculated by the formula (10)

$$m(t;\tau_1) = a_1 + b_1 lg(t-\tau_1), \tag{10}$$

where a1 = 1.091; b1 = 0.035 at $\tau_1 \le 28$ days.
$a_1 = 1.033$; $b_1 = 0.029$ at $\tau_1 > 28$ days.

The limiting values of the relative creep deformation and shrinkage of expanded clay concrete were determined by the method of constructing regression lines of the form

$$(t-\tau_1)\,/\varepsilon_{x,p}(t;\tau_1) = [A + B(t-\tau_1)]10^{-5}, \tag{11}$$

(according to GOST 24544-97), allowing to linearize curves describing creep deformations and shrinkage over time.

The numerical values of the coefficients A and B of equation (11) adopted to describe the curves of change in shrinkage deformation and creep during compression are given in Table 3.

Table 4 shows the results of a study of the creep deformation of expanded clay concrete under axial compression. As can be seen from the data obtained, the limiting value of creep deformations depended on the intensity of stress and increased as the level of long-term stress increased. It can be seen that the creep deformation was 75-90% of the ultimate creep deformation.

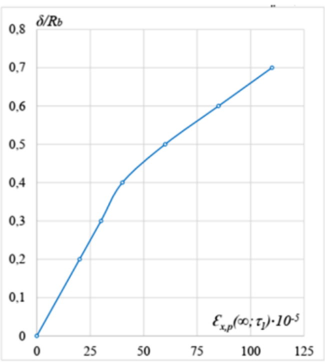

Figure 4. Change in creep limit deformations depending on the level of long-term load

Table 3

Results of statistical processing of tests (value of coefficients A and B)

σ_l/R_b	A	B
0,2	1,329	0,053
0,3	0,745	0,032
0,4	0,463	0,023
0,5	0,667	0,014
0,6	0,513	0,011
0,7	0,295	0,009
shrinkage	1,976	0,017

Table 4

Results of the study of creep deformation of expanded clay concrete under axial compression

σ_l/R_b	Deformation			
	elastic	creep	Limit	
	by the time the long-term load is applied	for 210 days	creep deformation	measure of creep
when compressing				
0,2	38	18	19	2.76
0,3	57	28	31	3.01
0,4	76	40	44	3.21
0,5	95	64	74	4.31
0,6	114	79	96	4.42
0,7	133	97	109	4.62

The results of determining the values of the functions (Table. 5) show that at stresses (0.2–0.4)R_b, the increase in strength and modulus of elasticity under compression was 6-15% and 1-5%, respectively, which is confirmed by the conclusions [7]. The hardening zone is shifted towards low stresses (0.2–0.4)R_b.

Table 5

The effect of previous loading on the strength and modulus of elasticity of concrete (Above the line – strength data, below the line – modulus of elasticity)

The value of the function m(t;τ_1) at the intensity of the preceding stresses					
$0,2R_b$	$0,3R_b$	$0,4R_b$	$0,5R_b$	$0,6R_b$	$0,7R_b$
1,13/1,03	1,09/1,05	1,06/0,97	0,90/0,78	0,90/0,78	0,88/0,76

DISCUSSION

The increase in the strength of compressed concrete can be explained by the removal of internal, redistribution of stresses between structural elements, which in turn equalizes the stress field due to the ongoing physico-chemical processes of hardening of cement stone, as well as some compaction of the concrete structure. High stresses ($\sigma/R_b \geq 0,5$) caused mainly a decrease in strength and modulus of elasticity, respectively, to 10-12% and 22-24%. (Large values correspond to large voltages). The decrease in the strength and modulus of elasticity of samples that have undergone prolonged compression can be explained by the fact that in the case of $\sigma/R_b \geq 0,5$, microcracks begin to appear in the samples.

Jointly analyzing the relationship between the creep limit deformations and the relative level of long-term stress (Fig. 4), we can reasonably conclude that the creep of expanded clay concrete at a loading level not exceeding $\sigma/R_b = 0,5$ can be considered conditionally linear, and the highest level of long-term stress, at which the short-term strength and modulus of elasticity of the main samples, those that have undergone prolonged compression do not differ from those for control twin samples $m(t;\tau_1) = 1$.

CONCLUSIONS

1. Empirical formulas for determining and describing the relative deformation of the nonlinear creep of expanded clay concrete (5), convenient for practical application, are proposed.

2. It is experimentally proved that the creep of expanded clay concrete under compression at a loading level of $\eta < 0,5$ is within the conditional linear dependence.

3. It was revealed that the previous effect of a prolonged compressive load of low intensity ($\eta < \cong 0,5$) increases the strength and elastic modulus of expanded clay concrete by 6-15% and 1-5%, respectively, and of high intensity ($\eta < \cong 0,5$) – reduces to 10-12% and 22-24%, respectively.

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