UDC 691.335: 69.01:624.01
DOI: 10.15587/1729-4061.2023.285183

IDENTIFYING THE INFLUENCE OF EXPANDED CLAY CONCRETE BASED ON A BINDER FROM PHOSPHORUS SLAG ON THE STRENGTH OF STRUCTURES FROM LEAKED CONCRETE

Bakirov Keles
Candidate of Technical Science, Associate Professor KOU, Academician of MAIN
Department of Transport Construction and Production of Building Materials
Academy of Construction, Architecture and Design
Caspian University
Saken Seifullin ave., 521, Almaty, Republic of Kazakhstan, 050000

Akmaral Sagybekova
Corresponding author
Candidate of Technical Science, Associate Professor*
E-mail: sagybekovaakmaral.8181@mail.ru

Abiyev Bakhytzhan
PhD, Associate Professor*

Ainash Karashina
Senior Lecturer, Master of Mechanical Sciences*

Akmaral Nurakhova
Senior Lecturer, Master of Mechanical Sciences*
*Department of Transport Construction and Production of Building Materials
Kazakh Automobile and Road Institute named after L. B. Goncharov (KazADI)
Raymbek str., 415V, Almaty, Republic of Kazakhstan, 050061

The paper presents the results of experimental studies of concrete and compressed reinforced concrete elements from cementless claydite-concrete. An experimental study of reinforced concrete elements with central and eccentric application of forces was carried out to determine their increased sensitivity. The construction material is cementless expanded clay concrete, obtained by a mixture of finely divided granular electrothermophosphorus slag. The tests were carried out on reinforced concrete compressed elements with central and eccentric application of longitudinal force to determine their bearing capacity. According to the test results, the strength and deformation properties of new concrete on a glass-slag binder and the calculation of reinforced concrete structures are checked.

The selection of compositions of glass-slag claydite-concrete of various grades has been made. The use of concrete with a clinker-free binder in construction makes it possible to reduce the need for a scarce building material – cement.

Studies of the physical and mechanical properties of glass-slag expanded clay concrete grades M50+M150 with a bulk density of 1,000–1,400 kg/m³ were carried out under a short-term static load. At the same time, the strength and deformation properties of glass-slag expanded clay concrete were studied under short-term action of compressive and tensile loads.

The use of any new building material must be preceded by a comprehensive study of it – determination of its strength properties, study of concrete in the structure under load, etc.

Building codes and regulations are adopted for the standard construction material, the properties of aggregates are not taken into account. Our studies show that the properties of fillers increase the strength properties of the structure when using claydite concrete on a glass-slag binder in reinforced concrete structures

Keywords: electrothermophosphoric, slag-alkaline binder, liquid glass, clinker-free binder, synergetic interaction, strength study

Received date 26.04.2023
Accepted date 17.07.2023
Published date 30.08.2023

How to Cite: *Keles, B., Sagybekova, A., Bakhytzhan, A., Karashina, A., Nurakhova, A. (2023). Identifying the influence of expanded clay concrete based on a binder from phosphorus slag on the strength of structures from leaked concrete. Eastern-European Journal of Enterprise Technologies, 4 (6 (124)), 51–58. doi: https://doi.org/10.15587/1729-4061.2023.285183*

1. Introduction

In the chemical industry, funds are spent on waste disposal, on average, about 8–10 % of the cost of circulation of the main product. At the same time, dumps, as a rule, surround natural resources, the environment and water bodies. The use of concrete with a clinker-free binder in construction makes it possible to reduce the deficit in the building material – cement.

The use of aggregates solves the issue of strength parameters, as well as saving the base material. The presence of a significant amount of industrial slag puts forward the difference in their complex use in the national economy. The solution to this problem may be the use of waste from phosphorus plants in building materials.

Therefore, studies that are devoted to the use of aggregates in the main material of structures today are of scientific relevance.

2. Literature review and problem statement

The work [1] presents the results of a study of phosphorus with excessive use of fertilizers and manure as one of the main sources of biogenic pollution has recently increased in wastewater as a result of intensive farming and industrialized and densely populated areas. The novelty of the current work is shown to be the improvement of the vertical aerated rock filter (VARF) using steel slag and limestone medium to improve the efficiency of the rock filter (RF) to remove total phosphorus (TP) from domestic wastewater. But issues related to the experimental study of efficiency and removal require further study in order to determine the best conditions for TP, taking into account unstable temperature and the presence of other contaminants that can adversely affect removal efficiency in unstable conditions. This approach is used in [2], however, in the chemical industry, on average, about 8–10 % of the cost of the main products produced is spent on waste disposal. At the same time, dumps, as a rule, occupy valuable agricultural land and serve as a source of industrial pollution of the atmosphere and water bodies.

In [2], the author suggests that reuse in valuable materials is one of the important approaches to the use of phosphorus tailings resources. At present, a mature technical system has been developed for the reuse of phosphorus slag in building materials and silicon fertilizers in the extraction of yellow phosphorus. But studies on the reuse of high-value phosphorus tailings have not been conducted. In order to ensure the safe and efficient use of phosphorus tailings resources, this study focused on how to solve the problem of light agglomeration and complex dispersion of phosphorus tailings micropowder when it was processed into road asphalt. In the experimental technique, the micropowder of phosphorus tails is treated in two ways. One method is to directly add it in varying amounts to asphalt to form a mortar.

All this makes it possible to state that corporate research on the presence of a significant amount of industrial slag puts forward the task of their integrated use in the national economy. The solution to this problem can be the use of waste from phosphorus plants in building materials.

The following is an analysis of the use of other additive materials. Each study shows the use of aggregates in the base material and provides parameters for calculating the strength of the structure.

In [3], the author proposes to experimentally investigate the effect of the content of shrinkage reducing agent (SRA) and the type of filler on the deformability characteristics of polymer concrete based on unsaturated polyester (UP) resin. In particular, set shrinkage, thermal expansion, maximum compressive strain and modulus of elasticity of polymer concrete UP were analyzed. However, the introduction of a slightly porous material as internal water reservoirs can reduce the strength and durability properties. On the other hand, cracking due to autogenous shrinkage has a significant negative effect on the durability of concrete. Studies on the durability of internally cured concretes with very low water-cement ratios are of great interest because there is very little information on this subject in the literature. The work studied the sensitivity to cracking of concrete made at a water-cement ratio of 0.21...0.33 and subjected to internal curing with a water-saturated light aggregate of volcanic origin (pumice) [4].

In order to reduce cracking, a strain hardening cement composite with strain hardening and multiple cracking properties was prepared to study the effect of interface roughness and repair layer thickness on shrinkage, cracking, and delamination patterns of concrete beams repaired [5]. The results show that under the action of shrinkage stress in the repair layer, instead of local fractures, multiple small cracks appear, and interfacial delamination is effectively controlled. However, it has a greater effect on the length of the interfacial delamination and the maximum delamination height of the repaired beam. With an increase in the roughness of the interface, the length of the delamination and the height of the repaired beam are significantly reduced. The results of this study can serve as a theoretical basis for the production and application of SHCC with high impact strength and low shrinkage.

The study [6] investigated columns made of reinforced concrete (RC) and strain-hardening cement composite (SCC) subjected to lateral loads in combination with a constant load, both experimentally and predictively, with two distributed inelastic finite element models set on stiffness and flexibility. Compared to experiments involving reinforced concrete columns and reinforced strain-hardened cement composite (R-SHCC), the current flex method has shown relatively accurate estimates of lateral loads and displacement responses of column systems, as well as localized non-linear cross-sectional responses. is evaluated by axial deformations of longitudinal steel reinforcing bars. Compared to the rigidity method, the current flexibility method gave more accurate solutions both at the elemental and constructive levels, which manifested itself in experiments and solution calculations.

This study [7] considers the possibility of improving the basic properties of concrete products by using a mixture of Portland cement and sulfoaluminoferritic clinker as a binder. It has been found that during the hydration of the binder, aluminate and ferruginous ettringite are formed, which increases the strength properties of concrete during normal hardening and thermal and wet treatment by increasing the strengthening structure. The main sign of hydration of sulfoaluminoferrite clinker is the stability of ferruginous ettringite, which provides compaction of the concrete structure. The density of the concrete structure, especially the contact zone, when using sulfated clinker, ensures non-shrinkage of concrete and eliminates shrinkage deformations, thereby increasing the crack resistance of concrete samples.

The results of studies of modern **binder composites** [8] opened the way for their wide use in construction. The introduction of short, discontinuous, and randomly distributed fibers into these composites altered their inherent **brittleness**. Extensive studies have been carried out on the effects of using monofilaments in a cement composite. However, limited reports are available in public sources on the use of hybrid fibers.

Further developments have recently been achieved through the development of ultra-high-performance cementitious composites. The issue of creating high- and ultra-high-cement composites using various types of fibers and particles is receiving great attention from the scientific community.

Almaty NIIstromproekt has developed a method for activating the binding properties of phosphorus production waste with substandard liquid glass, as a result of which a new clinker-free binder for concrete (author's certificate 425870), called glass-slag binder, has been obtained. The selection of compositions of glass-slag expanded clay concrete of various classes was made. The use of concrete with a clinker-free binder in construction makes it possible to reduce the need for a scarce building material – cement [9].

There is also experience with the use of aggregates in soil materials, as well as arguments in favor of parameters that take into account the requirements for aggregates.

The content of large soil fractions in the soil complicates the experimental part of the research, but the modeling method makes it possible to determine the effect of soil filler on slope stability. The paper presents the results of an experimental study of the strength of coarse clastic soils with different percentages of large fractions of gravelly soil (up to 20 *mm*) and aggregate (up to 5 *mm*) when studying the stability of slopes. The studies were carried out on three types of experimental equipment, which confirms the reliability of the results. Recommendations are given on the use of the values of the strength characteristics of coarse-grained soils when calculating the stability of slopes. The test results are carried out in the tray and shear testers. A mixture of soil fractions from 2 *mm* to 50 *mm* was used. The purpose of the tests is to determine the actual soil strength parameters j and C, taking into account the influence of impurities on the slope stability [10].

The reliability of the results was confirmed by the comparability of the results of previous tests [11–13].

In the analyzed scientific papers [1–14], various aspects of applying a filler to the main material of a structure are studied. An unexplored problem remains, the experimental justification for increasing the strength characteristics of the base material (concrete in our case) by aggregates. The application of the obtained strength characteristics allows you to make changes to the regulatory requirements of the standards.

The analyzed works show the use of aggregates in the base material. Each author of the following works, in his research on the use of placeholders, implements his own type. Of course, each study requires colossal work and time within the framework of the experimental part of the research. Due to the requirements of the experimental program, the conditions for selecting the material and type of aggregates, as well as the required time for conducting experiments, the analyzed studies do not cover all aspects of the statics and dynamics of the issue under study.

3. The aim and objectives of the study

The aim of the study is to determine the possibility of using expanded clay concrete based on a binder from phosphorus slag in building structures.

To achieve this aim, the following objectives are accomplished:

– to study the compressive strength of concrete;

– to study the impact resistance of concrete;

– to study the possibility of using additional payments or adjustments in the calculation formulas of building codes and regulations.

4. Materials and methods

The object of the study is compressed reinforced concrete elements from cementless expanded clay concrete.

Prototypes for studying the operation of elements of reinforced concrete structures were made from 4 batches of glass-slag expanded clay concrete. Expanded clay with a fraction of 5–20 mm was used as a coarse aggregate in all batches, a binder was liquid glass with a density of 1.3 g/cm^3 with a modulus of 1.8 and ground phosphorus slag, and a fine aggregate was quartz sand.

Simultaneously with the prototypes for the study of the strength and deformation properties of glass-slag expanded clay concrete under axial compression and tension, prisms with dimensions of 15×15×60 cm and cubes with edges of 15 cm were made from concrete of all 4 batches. The formation of prisms and cubes was carried out in groups in metal inventory cassettes. Before concreting, the inner surfaces of the formwork were smeared with a thin layer of oil. Compaction of the concrete mixture was carried out by a deep vibrator. After the end of vibrating, the excess concrete mixture was cut flush with the edges of the mold, followed by smoothing the surface with a trowel.

The molded samples were covered with wet sawdust over paper and stored for 4–5 days. After stripping, the prisms and cubes were again covered with wet sawdust. In this state, the samples were until the moment of their testing.

Before the start of the test, the prisms and cubes were subjected to a preliminary inspection, measurement of all geometric dimensions and weighing, after which the volumetric mass of concrete was determined.

When examining samples – cubes, the supporting faces were chosen, which will be adjacent to the press plates. The support faces were chosen so that the compressive force during the test was directed parallel to the layers of the concrete mix in the molds. For testing, the cube was installed on the lower support plate of the press centrally relative to its axis, using the risks marked on the plate. The load on the sample increased continuously at a constant rate of 4–6 kgf/cm^2 per second until its destruction. The maximum force achieved during the test was taken as the value of the breaking load. The tensile strength of concrete was calculated for each sample according to the formula:

$$R = \frac{N_p}{A}, \quad (1)$$

where N_p – breaking load;

A is the average area of the sample.

The results of tests of cubes and prisms are given in Table 1.

Table 1

Results of tests of cubes and prisms

Consumption of materials per 1 m^3 concrete, kg				Bulk weight, kg/m^3	R_{cube}/R_{pr}, MPa
Expanded clay	Sand	Phosphorus slag	Liquid glass		
210	190	180	130	1,030	2.98/1.83
320	190	180	130	1,030	2.98/1.83
300	190	180	130	1,030	3.02/2.57
250	190	180	130	1,030	3.02/2.57
300	190	190	130	1,060	4.8/3.06
250	190	180	130	1,030	5.31/3.3
360	240*	190	120	1,060	6.75/4.9
360	230*	220	160	1,120	8.6/7.42
370	290	270	180	1,350	10.88/7.84
240	290	270	180	1,350	9.4/7.6
410	340	250	130	1,300	12.9/10.32
400	240	290	200	1,400	14.6/11.05

*Note: *Expanded clay sand, for other compositions – quartz.*

Before the line – expanded clay fraction 5–10 mm, after the line – 10–20 mm.

Table 1 uses the following symbols:

R_{cube} – cube strength, for determining the brand of concrete, used in press (axial compression), dimensions 15×15×15 cm.

R_{pr} – prismatic strength, to determine the brand of concrete, press (axial compression), used in a sample with dimensions of 15×15×60 cm.

R_{cube}/R_{pr} – prismatic strength coefficient.

Normative data used in building standards use cube strength. We suggested the results indicated in Table 1 to use the prism strength, which is obtained by the ratio R_{cube}/R_{pr} cubic strength. R_{cube}/R_{pr} ratio gives the prism strength factor, which more accurately corrects the material strength.

Determination of prismatic strength, deformability and initial modulus of elasticity of glass-slag expanded clay concrete during compression was carried out on prisms with dimensions of 15×15×60 cm.

For testing, the prism was installed on the lower support plate of the press centrally relative to its axis, using the risks marked on the plate. Then the sample was centered at a load level equal to 25 % of the expected breaking force. When testing, the load on the prism was applied in steps until failure. The value of the first two steps was 0.05 of the expected breaking loads, then the step value was doubled. Starting from the 0.7–0.8 $N_{p\,step}$ increase in load stepping to failure, all subsequent loading steps were again reduced to 0.05*N_p – failure load in order to more accurately determine the magnitude of the breaking load. At each stage, the load was held for 3 minutes. Reports on the readings of strain gauges were taken before and after exposure.

The prism strength of concrete was determined by (1). Table 2 shows the characteristics and test results of prisms. A comparison of the experimental values of the prismatic strength coefficient from Table 2 with its values determined by the formula of Building codes and regulations was made [15]:

$$R_b=R\cdot(0.77-0.0001\cdot R). \qquad (2)$$

Fig. 1 shows that the experimental and standard values of the prism strength coefficient are close to each other.

Table 2

Compression test results for prisms

Batch number	Volumetric weight, kg/cm^3	Dimensions in cm			Breaking load in kN	Prism strength in MPa	
		a	*B*	*H*		in a separate	average
1	2	3	4	5	6	7	8
1st	1,070	14.9	14.58	59.9	75	3.45	3.3
	1,060	14.78	15.03	60.1	70	3.15	–
2nd	1,150	14.84	15.67	59.85	60	2.58	–
	1,140	14.82	14.64	59.9	53.5	2.46	2.57
	1,100	15.58	14.75	59.7	45	1.96	–
	1,170	15.07	14.86	60.1	60	2.68	–
3rd	1,220	15.01	15.05	60	41	1.81	1.83
	1,220	15.02	15.05	60	41	1.81	–
	1,220	15.0	15.05	60	42	1.86	–
4th	1,160	15.3	15.3	59.4	70	2.99	–
	1,150	15.0	15.4	58.9	75	3.20	3.06
	1,140	15.5	15.4	59.5	75	3.14	–

Note: a×b×*h – the cross-sectional dimensions of the samples for determining the strength by a prism; a – section length, b – section width, h – sample height*

Limiting longitudinal and transverse deformations averaged 1.8 ‰ and 0.4 ‰, respectively.

The initial modulus of elasticity of concrete in compression is determined by the formula:

$$E_б=\frac{\sum\Delta\sigma}{\sum\Delta\varepsilon_{ум}}, \qquad (3)$$

where $\Sigma_{\Delta\sigma}$ is the sum of stress increments at each stage from 0.05 N_p to 0.3 N_p;

$\Sigma_{\Delta\varepsilon\ ym}$ – the sum of increments of relative elastic-instantaneous deformation at each step within the same limits.

It is proposed to determine the initial modulus of elasticity for glass-slag claydite concrete according to the formula from [13] with the introduction of an adjustment – the coefficient 14.5 should be replaced by 8.5, which took the form:

$$E_b=8{,}5\cdot\gamma\cdot\sqrt[3]{R}, \qquad (4)$$

where E_b is the modulus of elasticity of concrete, tf/cm^2;

γ – bulk density, t/m^3;

R – cubic strength (concrete brand), kgf/cm^2.

Determination of the strength of concrete "R_{bt}" and its maximum deformation was carried out by testing prisms with dimensions of 15×15×60 cm for axial tension. Tensile testing of concrete prisms was carried out using special inventory devices, the traction bolts of which are screwed into a steel head, glued with epoxy resin to the cleaned ends of the prisms (Fig. 1).

Longitudinal deformations were measured using four strain gauges pasted on each face of the prototype. Before testing, the samples were centered with trial loads up to 0.2 N_p. Similarly, to test prisms for compression in axial tension, the load was applied to the sample in steps with a three-minute exposure.

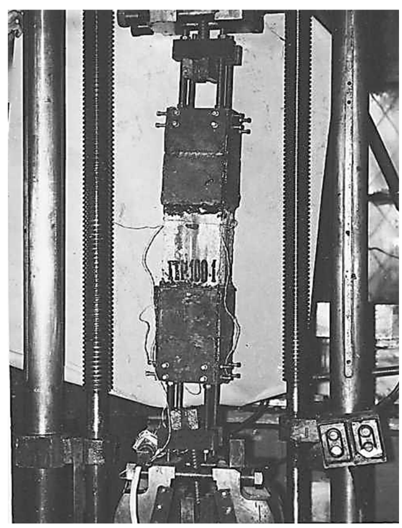

Fig. 1. Tensile test of prisms

The experimental value of the ultimate strength of glass-slag expanded clay concrete was determined by (1), but only in this case, N_p denoted the maximum load that caused the destruction of the prototype during central tension. The test was subjected to 3 prisms from each batch.

Characteristics of prototypes and the results of their tests are given in Table 3.

Table 3 shows that according to [8], the strength values R_{bt} of claydite concrete on a slag-alkaline binder are higher than in the experimental ones. Therefore, a change is introduced into the formula for determining the tensile strength of concrete.

$$R_{bt}^{T1}=0.5\sqrt[3]{R^2}. \qquad (5)$$

Table 3

Characteristics of prototypes and the results

R, MPa	R_{bt}^{op}, MPa	According to Building codes and regulations 2.03.01–84*R_{bt}, MPa	R_{bt}^{op} / R_{bt}	According to [1], R_{bt}^{T1}, MPa	$R_{bt}^{op} / R_{bt}^{T1}$	According to the formula (5) R_{bt}^{T2}, MPa	$R_{bt}^{op} / R_{bt}^{T2}$
2.98	0.4	0.345	1.16	0.48	0.83	0.35	1.14
4.8	0.54	0.521	1.03	0.66	0.82	0.48	1.12
6.75	0.63	0.683	0.92	0.83	0.76	0.6	1.05
14.6	0.99	1.197	0.83	1.93	0.71	1	0.99

Note: R – cube strength, MPa;
R_{bt}^{op} *– prismatic tensile strength of concrete obtained empirically;*
R_{bt} *– according to Building codes and regulations.*

Therefore, a change is introduced in the formula for the concentration density for sensitivity:

$$R_{bt}^{T2} = 0.36\sqrt[3]{R^2}, \qquad (6)$$

where R_{bt}^{T1} – standard strength according to Building codes and regulations;

R_{bt}^{T2} – tensile strength obtained experimentally.

The discrepancy between the experimental strength and its value calculated by the formula (6) is on average 4 %.

The maximum longitudinal deformations in axial tension were 0.22–0.24 ‰. The change in the strength of concrete did not have a significant effect on its deformability.

5. Results of experimental studies of concrete and compressed reinforced concrete elements from cementless claydite-concrete

5. 1. Operation of glass-slag expanded clay concrete in compressed reinforced concrete elements

To study the operation of glass-slag expanded clay concrete in compressed reinforced concrete elements, 10 columns were made with cross-sectional dimensions of 15×30 cm and a height of 70 cm. Longitudinal reinforcement consisted of 4 rods with a diameter of 16 mm, class A–III steel. Clamps made of steel class A–I with a diameter of 6 mm are supplied with a step of 100 mm. The supporting sections of the columns were reinforced with welded meshes and an end plate. Reinforcing cages were assembled in a conductor. Before assembling the frame, two pairs of strain gauges with a base of 20 mm were glued on the longitudinal reinforcement in the middle of its length, which was isolated with epoxy before concreting. The samples were concreted in a metal formwork. Concrete was laid in layers with compaction by a deep vibrator. The composition of concrete is given in Table 4.

When testing the prototypes, the longitudinal compressive force was applied with a relative initial eccentricity, divided by the height of the column section – relative eccentricityof 0.1; 0.2; 0.3; 0.4.

Table 4

Composition of concrete

Consumption of materials for 1 m^{3}concrete, in kg					Bulk weight, kg/m^3	Strength in MPa	
Expanded clay sand		Quartz sand	Phosphorus slag	Liquid glass			
5–10 mm	10–20 mm					cubic	prismatic
300	250	190	190	130	1,060	4.8	3.06
240	370	290	270	180	1,350	10.88	7.84

The reinforcement of the centrally compressed and the most compressed reinforcement of the eccentrically compressed columns at the moment of failure reached yield strains. At the same time, the compressed concrete also reached its limiting deformations. Table 5 shows the average values of the experimental breaking load of the tested columns for two twin samples and comparison with their standard values calculated according to Building codes and regulations 2.03.01–84*.

When studying concrete for compressive strength, it was revealed that the limiting longitudinal and transverse deformations of concrete during compression of average density are 1.8 ‰ and 0.4 ‰, respectively.

5. 2. Impact resistance of concrete

Table 5 shows the values using experimental strength indicators and calculated standard indicators of samples of reinforced concrete elements from expanded clay concrete on a binder from phosphorus slags based on a slag-alkaline binder.

Table 5

Average values of the experimental breaking load of the tested columns

Sample mark	Prism strength, MPa	Initial eccena tricity e_o, cm	N_p^{ex}, kN	N_p^{bc}, kN	N_p^{ex} / N_p^{bc}
K 1–0	3.06	0	495	464	1.07
K 1–3	3.06	3	395	370	1.07
K 1–6	3.06	6	315	301	1.04
K 1–9	3.06	9	282	256	1.10
K 1–12	3.06	12	215	223	0.96
K 2–0	7.84	0	748	748	1.00
K 2–3	7.84	3	680	595.7	1.40
K 2–6	7.84	6	640	492.5	1.30
K 2–9	7.84	9	610	421.6	1.45

e_o – initial eccentricity of longitudinal force application, cm;

N_p^{ex}, kN – experimental breaking load (compressive);

N_p^{bc}, kN – standard breaking load (compressive) according to Building codes and regulations;

N_p^{ex} / N_p^{bc} – the experimental values of the bearing capacity exceed the normative ones by an average of 5 %.

Table 5 shows that the experimental values of the bearing capacity exceed the normative ones by an average of 5 %. At the same time, the bearing capacity of the samples was determined without reducing the design resistance of the longitudinal reinforcement by multiplying by the coefficient of the reinforcement operating conditions for elements on porous fillers of classes B7.5 and below, recommended by Building codes and regulations 2.03.01–84* [13]. As you can see, with this type of concrete, there is no such need. The calculation of the strength of normal sections of compressed reinforced concrete elements made of expanded clay concrete on a slag-alkali binder can be carried out according to Building codes and regulations 2.03.01–84* [13–18], assuming the coefficient of reinforcement operating conditions equal to one.

The design tensile strength of expanded clay concrete on a slag-alkali binder should be determined by the formula (7).

5. 3. Design indicators of building codes

Table 6 presents data on the limits of longitudinal and transverse deformation of concrete during compression.

Table 6

Column test results

Sample mark	R_{pr}, MPa	Dimensions in cm			Reinforcement		e, cm	Experienced		Building codes and regulations 2.03.01–84*		$\frac{N_p^{ex}}{N_p^{bc}}$
		b	h	a'	$A_s = A_s^{'}$	σ_y, MPa		σ_s^{ex}, MPa	N_p^{ex}, kN	σ_s^{bc} MPa	N_p^{bc}, kN	
K 0–1	3.112	15.08	29.4	–	7.64	424.0	–	–424.0	480	–424	461.91	1.04
K 0–2	3.112	15.2	29.75	–	7.64	424.0	–	–424.0	510	–424	464.66	1.1
K 3–1	3.112	15.2	26.1	3.1	3.82	424.0	14.35	–288	390	–249.2	371.23	1.05
K 3–2	3.112	14.6	26	3.4	3.82	424.0	14.18	–232	400	–248.0	365.81	1.09
K 6–1	3.112	14.8	26.3	3.5	3.82	424.0	17.4	–92	320	–94.6	301.9	1.06
K 6–2	3.112	14.8	26.5	3.6	3.82	424.0	17.6	–80	310	–90.0	300.7	1.03
K 9–1	3.112	14.8	26.2	3.2	3.82	424.0	20.4	12	270	7.0	257.4	1.05
K 9–2	3.112	14.6	26.4	3.5	3.82	424.0	20.6	40	295	13.1	254.14	1.16
K 12–1	3.112	14.8	26.2	3.2	3.82	424.0	23.4	–	210	85.1	223.45	0.94
K 12–2	3.112	14.6	26.3	3.1	3.82	424.0	23.5	40	220	82.8	223.53	0.98

Table 6 uses the following symbols:

b – section width, cm;

h – section height, cm;

a' – reinforcement cover, cm;

A_s – cross-sectional area of less compressed reinforcement, cm^2;

$A_s^{'}$ – sectional area of compressed reinforcement, cm^2;

σ_y – reinforcement yield stress, MPa;

e – eccentricity, the distance from the neutral axis to the point of application of the load, cm;

σ_s^{ex} – experimental stress in the armature, MPa;

N_p^{ex} – experimental breaking load, kN;

σ_s^{bc} – normative stress in reinforcement, MPa;

N_p^{bc} – standard breaking load, kN;

$\frac{N_p^{ex}}{N_p^{bc}}$ – the ratio of experimental and normative breaking loads gives us a value equal to approximately 1.

The initial modulus of elasticity of glass-slag expanded clay concrete is lower than that of conventional concrete and is well described by the proposed dependence

$$E_b = 8.5 \cdot \sqrt[3]{R}. \quad (7)$$

6. Discussion of application of claydite-concrete strength parameters to improve the quality of building structure

We have found that the ratio of the strength parameters obtained experimentally and those obtained by calculation according to the normative document N_p^{ex} / N_p^{bc}, will help us specify the design characteristics for calculation.

Here, N_p^{ex} / N_p^{bc}, where N_p^{ex} is the strength of the column, obtained experimentally; N_p^{bc} – strength of the column obtained by calculation according to the formulas of the normative document 2.03.01–84* "Concrete and reinforced concrete structures".

Structures made of a glass-slag binder were considered similarly to ordinary lightweight expanded clay concrete. The calculation of compressed and bent structures made of glass-slag expanded clay concrete was carried out according to generally accepted formulas of regulatory documents, i.e. according to building codes. When studying concrete for compressive strength, it was revealed that the limiting longitudinal and transverse deformations of concrete during compression of average density are 1.8 ‰ and 0.4 ‰, respectively (Table 2).

According to the results of the experimental study, the following was found:

1. The design tensile strength of expanded clay concrete on a slag-alkali binder should be determined by the formula (6).

2. The initial modulus of elasticity of glass-slag expanded clay concrete is lower than that of conventional concrete and is well described by the proposed dependence (7).

The results of tests for the strength of concrete in compression of reinforced concrete elements with the central and eccentric application of a proportional force to determine their absorption capacity allow using the possibility of measuring the reinforcement density coefficient for elements on porous aggregates equal to 1.

Based on the results of the identified tests, the resistance to a specific impact, which manifests itself in the fact that the experimental values show the tested abilities of the samples, exceeds the standard resistance by an average of 5 % (Table 6).

The possibility of using surcharges or adjustments in the calculation formulas of chemical norms and rules was obtained experimentally. At the same time, the bearing capacity of testing the column is observed without assessing the resistance of the proportion of reinforcement, which causes multiplication by Sensitivity of the reinforcement performance coefficient.

The use of various materials in the form of resin and industrial waste makes it possible to realize the possibilities of concrete as a structure and at the same time increase its strength. The possibility of increasing the resistance to structural loads makes it possible to change the standard coefficients.

The test results are presented in Table 5, which show that the experimental values of the endurance of the tested samples exceed the standard endurance by an average of 5 %.

At the same time, the bearing capacity of testing the column is observed without assessing the resistance of the proportion of reinforcement, which causes multiplication by Reduction in the reinforcement performance coefficient for elements on porous aggregates of classes B7.5 and below, recommended by Building codes and regulations.

The test results are shown in Table 6, which indicates that the experimental values of the bearing capacity of the tested samples exceed the standard strength by an average of 5 %.

At the same time, the bearing capacity of the experimental columns was determined without reducing the design resistance of the longitudinal reinforcement by multiplying by the reducing coefficient of the operating conditions of the reinforcement for elements on porous aggregates of classes B7.5 and below, recommended by Building codes and regulations 2.03.01–84*. As you can see, with this type of concrete, there is no such need. Therefore, the calculation of the strength of normal sections of compressed reinforced concrete elements made of expanded clay concrete on an alkali-slag binder should be carried out according to Building codes and regulations, assuming the coefficient of reinforcement operating conditions equal to 1.

These studies were carried out under short-term static load. Therefore, it is necessary to continue research on structures made of glass-slag claydite-concrete under long-term and dynamic impacts.

7. Conclusions

1. The ratio between the prism and cubic strength of glass-slag expanded clay concrete is in good agreement with the dependence set forth in Building codes and regulations 2.03.01–84*.

2. The limiting longitudinal and transverse deformations of concrete during compression are on average equal to 1.8 ‰ and 0.4 ‰, respectively. The design tensile strength of expanded clay concrete on a slag-alkali binder should be determined by the formula $R_{bt} = 0.36\sqrt[3]{R^2}$.

3. The initial modulus of elasticity of glass-slag expanded clay concrete is lower than that of conventional concrete and is well described by the proposed dependence.

$E_б = 8.5 \cdot \sqrt[3]{R}$. The bearing capacity of compressed elements on a glass-slag binder is recommended to be taken without reducing the design resistance of longitudinal reinforcement by multiplying by the coefficient of reinforcement operating conditions, as is customary for elements on porous fillers of classes B7.5 and below in Building codes and regulations 2.03.01–84*.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The study was performed without financial support. The authors are using own funds.

Data availability

The manuscript has data included as electronic supplementary material.

References

1. Maarup, S. N., Hamdan, R., Othman, N., Al-Gheethi, A., Alkhadher, S., El-Hady, M. M. A., Saeed, S. E.-S. (2023). Steel Slag and Limestone as a Rock Filter for Eliminating Phosphorus from Domestic Wastewater: A Pilot Study in a Warm Climate. Water, 15 (4), 657. doi: https://doi.org/10.3390/w15040657
2. Xiao, Y., Ju, X., Li, C., Wang, T., Wu, R. (2023). Research on Recycling of Phosphorus Tailings Powder in Open-Graded Friction Course Asphalt Concrete. Materials, 16 (5), 2000. doi: https://doi.org/10.3390/ma16052000
3. Yeon, J. H., Lee, H. J., Yeon, J. (2020). Deformability in Unsaturated Polyester Resin-Based Concrete: Effects of the Concentration of Shrinkage-Reducing Agent and Type of Filler. Materials, 13 (3), 727. doi: https://doi.org/10.3390/ma13030727
4. Kovler, K., Zhutovsky, S. (2012). Crack Resistance and Durability-Related Properties of Internally Cured High-Strength/High-Performance Concrete. 3rd International Conference on the Durability of Concrete Structures. Queen's University Belfast. URL: https://www.researchgate.net/publication/286521231_Crack_resistance_and_durability-related_properties_of_internally_cured_high-strengthhigh-performance_concrete
5. Wang, P., Jiao, M., Hu, C., Tian, L., Zhao, T., Lei, D., Fu, H. (2020). Research on Bonding and Shrinkage Properties of SHCC-Repaired Concrete Beams. Materials, 13 (7), 1757. doi: https://doi.org/10.3390/ma13071757
6. Cho, C.-G., Lee, S.-J. (2021). Inelastic Responses and Finite Element Predictions of Fiber Cementitious Composite and Concrete Columns. Materials, 14 (9), 2180. doi: https://doi.org/10.3390/ma14092180
7. Samchenko, S., Krivoborodov, Y. (2019). Improving crack resistance of concrete when using expanding cements. IOP Conference Series: Materials Science and Engineering, 687 (2), 022039. doi: https://doi.org/10.1088/1757-899x/687/2/022039
8. Khan, M. I., Abbas, Y. M., Fares, G. (2017). Review of high and ultrahigh performance cementitious composites incorporating various combinations of fibers and ultrafines. Journal of King Saud University - Engineering Sciences, 29 (4), 339–347. doi: https://doi.org/10.1016/j.jksues.2017.03.006
9. Bakirov, K. K., Esenbaeva, A. N. (2014). Local compressive strength of cementless expanded clay concrete. Materials of the X International Scientific and Practical Conference "Science before Europe - 2014". Vol. 30. Ecology. Geography and Geology. Przemysl, 102–105.
10. Sagybekova, A., Kiyalbay, S., Belov, A., Kiyalbayev, A., Tursumbekova, K. (2022). Comparison of test results to determine the parameters of soil strength to ensure the stability of earth slopes. EUREKA: Physics and Engineering, 6, 3–11. doi: https://doi.org/10.21303/2461-4262.2022.002691

11. Bek, A. A. (2019). Observations of deformations of engineering structures with the help of modern high-precision geodetic devices. AD Alta: Journal of Interdisciplinary Research.
12. Yessentay, D. (2021). Reliability criterion for calculation of the optimum driving speed on road in winter. International Journal of GEOMATE, 21 (83). doi: https://doi.org/10.21660/2021.83.j2115
13. Zhussupbekov, A., Tulebekova, A., Zhumadilov, I., Zhankina, A. (2020). Tests of Soils on Triaxial Device. Key Engineering Materials, 857, 228–233. doi: https://doi.org/10.4028/www.scientific.net/kem.857.228
14. Baikov, V. N., Sigalov, E. E. (2018). Reinforced concrete structures. Textbook for high schools. Moscow.
15. Lightweight concrete on porous aggregates. Methods for determining strength and volumetric weight. Government Standard 11050-64.
16. Building codes and regulations 2.03.01-84*. Design standards. Concrete and reinforced concrete structures.
17. Glukhovsky, V. D. (Ed.) (2005). Slag-alkaline concretes on fine-grained aggregates. Kyiv.
18. Gvozdeva, A. A. (Ed.) (2018). New in the design of concrete and reinforced concrete structures. Moscow.