Short-term and Long-Term Deformations of the Lightweight Concrete

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Abstract. The article is devoted to the study of the short-term and long-term deformations of the lightweight concrete which has found ever-growing use in various fields of construction. The main direction of the lightweight concrete usage is its application in the load-bearing and enclosing structures of buildings and structures. The lightweight concrete has fundamental differences from heavy weight concrete and this is primarily due to the special characteristics of the porous aggregates in their composition. Concretes with such aggregates as expanded clay, expanded perlite and agloportite with strength from 10 to 60 mPas, whose deformative properties are represented by the stress – strain diagram in fig.1, have been investigated in this work. The dependence of the diagrams completeness on the type of aggregate at various concrete strength indexes is given in Table 1. The ascending branches of the diagram for the whole range of the strength has ended when a deformation has reached 2,2 $\times$ 10³. The concrete stress corresponding to the limiting compressive strain of all types of concrete has been 85% of the maximum value. All the diagrams intersect at one point, the descending branches diverge at a stress level of 0.75 and the deformations have been 2,9…3,7 $\times$ 10³. The data obtained as a result of the investigation can be used to calculate the normal sections of bending and eccentrically compressed elements with allowance made to the properties of the lightweight concrete that significantly expand its promising applicable scope in areas with complex geological conditions and in seismic areas.

1. Introduction

It is advisable to use the light concrete for enclosing and supporting structures and primarily for the exterior walls and other enclosing structures (for example for slabs and attic floorings) in residential and public as well as in heated industrial and agricultural buildings due to its low density, good thermal properties, sufficiently high strength and durability. Bearing structures made of the lightweight concrete are up to two times lighter than that of heavy concrete due to their lower density which is 1.5 times fewer when using durable lightweight sand as fine aggregate.

The expediency of their use is also due to the low cost of the porous aggregates. The multipurpose use of the lightweight concrete for enclosing and bearing structures allows additional savings of money and expensive raw materials by simplifying the production and use of the local resources [9].

Coarse and fine porous aggregates such as unburned, made from industrial waste, natural and calcined materials are used in the production of the lightweight concrete. Other types of effective
porous aggregates, that have standards or specifications, may also be used. All porous aggregates must meet the GOST 9757-90 Gravel, gravel and sand artificial porous requirements. Technical conditions (with the Alteration N 1).

The following types of the lightweight concrete have been ascertained according to the type of large porous aggregates: expanded clay concrete, shungizite concrete, agloporite concrete, slag concrete, perlite concrete, crushed-stone concrete with porous rock, vermiculite concrete, cinder concrete (concrete with the furnace clinker or porous dump smelter slag, cinder block or agloporite).

Metallurgical waste substances, energy, forestry industries (including those obtained from wood processing) and agriculture as well as natural porous materials can be used as unfired aggregates. In such a case it is advisable to use

a) metallurgical waste substances (blast-furnace and steel-smelting slags) - for the manufacture of slag pumice of porous slag-and-sand sand and with the appropriate justification of the granulated slag. Slag pumice (in the form of crushed stone) is recommended to be used as coarse and fine aggregate while porous slag and pumice sand and granulated slag is recommended to use only as fine aggregate.

b) waste substances of the energy industry in the form of ash and slag mixture – as an aggregate for the fine grained concrete and as fine aggregate for the coarse-grained lightweight concrete.

c) waste substances of the forest and wood processing industry are used for the manufacture of an aggregate in the form of hogged chips while agricultural waste substances are used for the production of crushed cotton plant stems, rice straw, hemp and flax awnchaff.

d) natural porous aggregates in the form of pumice, tuff, volcanic slag and shell limestone are advisable to use as coarse and fine aggregates. With that first of all, waste products from the extraction of the porous dimension stone should be used for processing into porous aggregates.

Fired aggregates are recommended to be made from various types of clays and tripoli, perlitic rocks, ashes and slags of thermal power plants, subsurface rocks and other materials. The most appropriate is to produce aggregates:

a) from clay, depending on its quality, coarse and fine porous aggregates - expanded clay gravel and sand, agloporit gravel and sand, as for the aggregates from shist - schungizite gravel and shungizite sand obtained by crushing schungizite gravel.

b) from tripoli depending on their quality - thermolith crushed stone or gravel that can be used as coarse and fine aggregate. Thermolith sand is produced by crushing thermolith crushed stone or gravel;

c) from perlite rocks - expanded pearlitic sand and crushed stone;

d) from ashes and slags of thermal power plants (if necessary) - varieties of claydite - ash gravel, agloporit gravel, clay and ash claydite;

e) from non-bloating loam, ashes of thermal power plants, blown sand, subsurface rock and other industrial product wastes - azerite gravel and sand. The latter is obtained by crushing azerite gravel. Despite the sheer magnitude of concrete structures based on the lightweight aggregates, their use is constrained by the insufficient study of their behavior under the short and long-term application of external loading [10]. Further study of their behavior will contribute to a more reliable evaluation of the stress-strain state of structures and consequently, their more rational design [13].

2. Topicality

Currently available information on the mechanical properties of the lightweight aggregates does not fully explain the researchers’ contradictory experimental data on the type of compression, elasticity, creep deformations and nature of the destruction of the lightweight concrete.

The lightweight concrete has fundamental differences from the conventional heavy concrete due to the porous aggregates particular qualities. The latter has a lower density, lesser strength, often below a defined concrete grade and a highly developed and rough surface. These qualities of the lightweight aggregate affect both the properties of the lightweight concrete mixtures and the properties of concrete.
The deformative properties of the lightweight concrete have been represented by the type of the “stress – strain relationship” that depends on the strength of the concrete, the aggregates properties and the concrete composition [5]. The compressed concrete” stress – strain relationship”, based on the extensive experimental material accumulated by researchers, has been taken according to a system of the specified parameters in graphics. The stress- strain relationship for the representative points of the curves corresponding to the maximum concrete stress, ultimate strain and initial loading for estimating the elastic properties of concrete by the elasticity modulus have been taken into account.

A lot of different equations based on the power dependence, parabolic and hyperbolic laws as well as more complex equations have been proposed for the analytical expression of the concrete compression diagrams in connection with the development of the computational methods. In the overwhelming majority of cases these equations have not been meant to reveal the physical meaning of one or another deviation from the linear dependence; the only aim has been to describe the curve externally that best corresponded to the experiments.

Below are some generalized data on the concrete based on the following porous aggregates: expanded clay, expanded perlite, agloporite.

3. Research methodology

It is known that regardless of the nature of the work strain, an internal field of the true stresses and strains, that repeat the degree of difference in the aggregate elastic modulus and the permanent material in the lightweight concrete, appears there. All models had the same geometric dimensions – they were cubes with a face of 100x100x100 mm [4]. Three series of five samples of the lightweight concrete models were manufactured. The base of all the models was the same and consisted of a 1: 1 sand-cement mortar and a W / C ratio of 0.4. At the same time Portland cement of 500 grade of cement and river sand were used.

Sample tests of all kinds of concrete were carried out at the age of 28 days [11]. The compressive load was transferred on one of the cubes surfaces using a P-50 hydraulic press with the manual control. Figures 1 and 2 show tests of one of the lightweight concrete samples in the laboratories of Vladimir State University.

![Figure 1. Test of the lightweight concrete samples by means of the press.](image)

Loading was carried out in steps of 0.1 of the expected compressive strength up to its disintegration. At each stage of loading a five-minute time limit was given in order to take readings. Structural changes of the concrete under loading were controlled by measuring the longitudinal and lateral strains [6].
4. The result

Figure 2 shows the diagrams based on the results of the statistical processing of experiments with concrete on lightweight artificial aggregates with a strength of 10 to 60 MPa. The elasticity modulus ranges from \(26 \cdot 10^3\) to \(39 \cdot 10^3\) MPa [15]. As the grade of the concrete rises, the initial concrete modulus increases and the ultimate compressibility decreases [14]. The ascending branches of the diagram” \(\sigma - \varepsilon\) “for the whole range of strength ended when the deformation was equal to \(2.2 \cdot 10^3\), that corresponded to the ratio \(\sigma_b / R_b = 0.85\) [1]. All the diagrams intersect at one point, the descending branches diverge at a stress level of 0.75 and the deformations were \(2.9 \ldots 3.7 \cdot 10^3\) [2].

![Diagram](image.png)

The diagrams are characterized by different completeness \(w\), the lower the strength of the lightweight concrete, the greater is the completeness [7]. Dependence of the diagram completeness” \(\sigma - \varepsilon\) “on the type of the aggregate for various indexes of concrete strength is given in Table 1.

| The lightweight aggregate concrete in the Russian Federation districts | Completeness of the diagram under the concrete strength, MPa |
|---------------------------------|-----------------|
|                                 | 10              | 20              | 30              | 40              | 50              | 60              |
| Expanded clay                   | 0.71            | 0.68            | 0.66            | 0.63            | 0.6             | 0.57            |
| Expanded perlite                | 0.69            | 0.62            | 0.61            | 0.56            | -               | -               |
| Agloporit                        | 0.67            | 0.6             | 0.52            | -               | -               | -               |

With a known approximation \(w\), can be used to figure out standard normal and sloping sections. Completeness of the diagram and maximum deformations on the descending branch depend on many factors: type of the aggregate, concrete composition and structure, etc. [8]. Quality of sand has a significant impact on the concrete deformability. When the sand content is from 33 to 66% of the volume of the coarse lightweight aggregate, fullness of the diagram varies depending on the strength within the range of 0.66 ... 0.54.
Comparison of the theoretical and experimental diagrams has shown that the latter are satisfactorily described using the previously proposed methodology. In general, the system for describing the concrete diagram looks as (1):

\[ \sigma_b(\varepsilon_b) = \sigma_{bi} + \sum_1^3 m_i \cdot (\varepsilon_b - \varepsilon_{bi})^n \]  (1)

The following notations are introduced in the formula (1): \( \sigma_b(\varepsilon_b) \) - stresses and deformations at the vertex of the concrete deformation diagram under the off-center compression; \( \sigma_{bi} \) and \( \varepsilon_{bi} \) - stresses and strains at the i-th point; \( m_i \) - trial coefficient depending on the type of concrete.

Parametric points of the concrete state have been assigned as the supporting (according to O.Ya. Berg) [3]. Creep and shrinkage have been determined on prisms 15x15x60 cm and 5x15x45 cm. The powder density of the lightweight aggregates has been 440-845 kg / m\(^3\), the density of grains has been 830-1250 kg / m\(^3\). The final creep characteristics of some types of concrete are given in Table 2.

| Type of the aggregate | Creep deformation at the age of 2 years, \( \varepsilon_k \cdot 10^6 \) | Creep measure, \( C_k \cdot 10^{-6} \) MM\(^2\)/H |
|-----------------------|-----------------------------|-----------------------------------------|
|                       | \( \eta = 0,25 \)   | \( \eta = 0,4 \)   | \( \eta = 0,25 \)   | \( \eta = 0,25 \)   |
| Expanded clay         | 520                      | 810                       | 108                    | 105                    |
| Expanded perlite      | 522                      | 635                       | 60                     | 62                     |
| Agloporit             | 635                      | 1030                      | 77                     | 78                     |

where \( \eta \) is the stress level.

The shrinkage data have been processed and grouped out depending on the strength of the lightweight aggregate and cement consumption [12, 16]. The shrinkage deformation for 2 years has been \( 55 \cdot 10^{-5} \). Processing the results using the least square technique has shown the possibility of describing shrinkage deformations by a simple function of the form (2):

\[ \sigma_y = K \cdot t \cdot (m + t) \]  (2)

where \( t \) is the time, days, \( K \) and \( m \) are experimental coefficients depending on the type of concrete.

5. Conclusions

In the conducted studies, the deformative features of concrete with porous aggregates under a variety of strengths have been studied, the following main conclusions, based on the results of the research conducted, can be made:

1) In connection with the development of the computational methods for the analytical expression of the lightweight concrete compression diagrams, many different equations based on power dependencies, parabolic and hyperbolic laws, as well as more complex equations have been proposed;
2) Creep is characteristic of the porous aggregates. This must be taken into account when evaluating the creep of the lightweight concrete;
3) Known deformation models reflect only short-term load effects. For long processes it is necessary to introduce additional conditions that take the problems of creep into account [14];
4) The obtained and processed data can be used to calculate the normal sections of bending and beam column taking the properties of the lightweight concrete into account;
5) The “stress – strain” dependences for the lightweight concretes, differing in the character of the convexity of the deformation diagram, have been established;
6) The conducted research in the field of investigation of the strength and deformation properties of concrete on the lightweight aggregates will significantly expand its application domain.
Reference

[1] Ezzi H, Roschina S I, Lukin M V 2016 Calculation of stressed deformation condition of reinforced concrete ribbed plate coating taking into account interaction with rigel BST: bulletin of building technology 4(980) pp 38-40

[2] Ezzi H, Roschina S I, Rimshain V I 2016 Experimental researches of joint deformation of reinforced monoplate construction with coating plates BST: bulletin of building technology 4(980) pp 35-37

[3] Karpenko N I, Eryshev V A, Rimshin V I 2018 The Limiting Values of Moments and Deformations Ratio in Strength Calculations Using Specified Material Diagrams IOP Conference Series: Materials Science and Engineering 463(3) 032024

[4] Krishan A L, Rimshin V I, Astafeva M A 2018 Deformability of a Volume-Compressed Concrete IOP Conference Series: Materials Science and Engineering 463(2) 022063

[5] Krishan A L, Rimshin V I, Troshkina E A 2018 Strength of Short Concrete Filled Steel Tube columns of Annular Cross Section IOP Conference Series: Materials Science and Engineering 463(2) 022062

[6] Maximov I N, Makridin N I 2014 Building material science construction light concrete PGUAS (Penza) p 214

[7] Roschina S, Ezzi H, Shishov I, Lukin M, Sergeev M 2017 Evaluation of the deflected mode of the monolithic span pieces and preassembled slabs combined action IOP Conference Series: Earth and Environmental Science 90(1) 012075

[8] Roschina S I, Lukin M V, Lisyatnikov M S, Sergeyev M S 2017 Reconstruction of coating by a single-stage adjustment of a lind-fitting factory in the city of vyazniki Izvestiya Vysshikh Uchebnykh Zavedenii, Seriya Teknologiya Tekstil’noi Promyshlennosti 370(4) pp 226-230

[9] Roschina S I, Ryazanov M A, Shishov I I, Repin V A 2017 Theoretical and experimental determination of probibes of ribbed plates in the composition of assembly-monolithic coating of industrial building Construction and reconstruction 5(73) pp 50-57

[10] Ryazanov M A, Shishov I I, Roschina S I, Smirnov E A, Sergeev M S 2016 Experimental research of work of the meeting-monolithic coating of a production building BST: bulletin of building technology 12(988) pp 57-61

[11] Spathelf C A, Vogel T 2018 Fatigue performance of orthogonally reinforced concrete slabs: Experimental investigation Engineering Structures 168 pp 69-81

[12] Varlamov A, Rimshin V, Tverskoi S 2019 A method for assessing the stress-strain state of reinforced concrete structures E3S Web of Conferences 91 02046

[13] Varlamov A A, Rimshin V I, Tverskoi S Y 2018 The modulus of elasticity in the theory of degradation IOP Conference Series: Materials Science and Engineering 463(3) 022029

[14] Varlamov A, Shishlonov E, Tkach E, Shumilin M and Goncharov D 2016 Regularity of stress connection and deformation in concrete Academy 2(5)

[15] Yasser E Ibrahim 2018 Assessment of a cracked reinforced concrete beam: Case study Case Studies in Construction Materials 9 e00179

[16] Pesterev A P, Vasilyeva A I, Ammosova M N, Solovev D B 2018 Unexplored soils of the Western Yakutia IOP Conference Series: Materials Science and Engineering 463 paper № 022001. [Online]. Available: https://doi.org/10.1088/1757-899X/463/2/022001