Improvement directions of technical regulations in the field of reinforced cellular concrete structures

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\textbf{Abstract.} Effective management of real estate complexes, which determines the rational capital intensity of ownership of buildings and structures, largely depends on the consumer qualities of building materials and products included in the investment and construction project at the design stage. The implementation of the principles of rational design, which are regulated in unique and technically complex and responsible structures, is still not properly reflected in the design of second-class objects of responsibility, which, however, make up more than 70\% of the capital intensity of the construction market, mainly housing. Complex composite materials that combine innovative and energy-efficient components and technologies, as well as structures made from them that contain significant reserves of load-bearing capacity, which are opened and implemented by improving design standards and rational technical solutions, have the greatest potential for rationalization. Reinforced cellular concrete, which effectively combines load-bearing and enclosing functions, is one of the most popular construction technologies in the perspective practice of low-rise construction. Currently, however, the design of reinforced structures made of cellular concrete in Russia, abroad, mainly performed according to the normative documents, often not taking into account the significant differences in physical and mechanical properties, material structure, principles and working mechanisms of various types of concrete under load, as well as the uniqueness of plastic properties of cellular concrete when assigning the form and composition of discrete reinforcement. In this regard, there is a need to revise and systematize existing standards that contain requirements for the design of directly reinforced structures made of cellular concrete, generalize European experience and these standards, update information in them, as well as develop modern national standards in this area. In addition, the practice of designing bent cellular concrete structures has revealed a significant reserve for increasing the load-bearing capacity of these elements, associated with insufficient inclusion of the material of the traditionally used rod reinforcement due to the primary destruction of the contact layer (pulling the reinforcement). In order to increase the durability and reduce the resource intensity of national cellular concrete structures, the adopted methodology for their design needs to improve both the regulations that establish the principles and rules for calculating reinforcement elements of structures, and structural elements used in precast and in-situ practice of discrete reinforcement.
1. Introduction
Rational design of load-bearing and enclosing structures, which is an essential and integral part of effective management of real estate complexes, is supported by the principles and rules of rational design in the current technical regulations. Modern national standards for the design of cellular concrete structures are reflected in a variety of existing guidelines of the regulatory framework of the Russian Federation in this area. They are represented by codes of rules, state standards, technical requirements and instructions, as well as building codes and some other manuals that establish requirements for the calculation and design of concrete and reinforced concrete structures of industrial and civil buildings and structures.

2. Materials and methods

2.1. Materials
To date, the design of reinforced structures made of cellular concrete is mainly carried out according to regulatory documents that extend their effect and establish the same requirements for the design of concrete and reinforced concrete structures made from various types of concrete: heavy, fine-grained, light, cellular and straining [1]. However, it is worth noting that these rules do not take into account the significant differences in physical and mechanical properties, material structure, principles and working mechanisms of various types of concrete under load, as well as the uniqueness of plastic properties of cellular concrete, much different from the properties of heavy concrete. Thus, the basic requirements for finished cellular concrete products are similar to those for reinforced concrete structures made of heavy concrete, designed according to classical theories and models for calculating reinforced concrete, based on experimental data and laws of mechanics applicable to all types of concrete.

At the same time the requirements of SP 63.13330 do not apply to the design of structures made of concrete with an average density of less than 500 kg/m³, although many structures made of cellular concrete used in low-rise construction have a significantly lower density, and therefore cannot be calculated on the basis of this document, and the design of such structures must be carried out in accordance with relevant regulatory documents, such as SP 339.1325800.2017 “Structures made of cellular concrete. Design rules”, first introduced only in 2018 [2, 3]. This code applies to the design of concrete and reinforced concrete products made from precast cellular concrete, as well as to the design of reinforced monolithic structures intended for civil buildings. According to p. 4.2.1 of SP 339.1325800 “…basic design requirements for the design of stone, concrete and reinforced concrete structures made of cellular concrete are accepted in accordance with SP 63.13330, SP 15.13330…” while this document provides a set of generalized requirements for the design of structures made of cellular concrete.

Also taking into account the periodic temporal extension of separate regulations to develop new or in connection with the cancellation, the introduction of relevant amendments to existing ones, it is often necessary to make use of outdated design guidelines, such as, a Manual for design of concrete and reinforced concrete structures made of cellular concrete (to BCR 2.03.01−84), approved by Gosstroy of the USSR on April 16, 1985, № 20, or Guidelines for the design of concrete and reinforced concrete structures made of cellular concrete, 1977 [4]. These documents contain the main design requirements, regulatory and design characteristics of materials, a complete list of methods for calculating elements of concrete and reinforced concrete structures made of cellular concrete according to the limit states of the first and second groups, while in SP 339.1325800.2017 “Structures made of cellular concrete. Design rules” only the requirements for these types of calculations are presented [5, 6, 7].

2.2. Methods
Standards for the design of cellular concrete structures are considered and presented in a variety of national documents, which often refer to each other, have incoherence and inconsistency, which
causes a discrepancy in the understanding of the main design requirements [8, 9]. All this causes modern problems in the rational design of reinforced cellular concrete and, as a result, the need to integrate and harmonize the regulatory framework of technical regulation in this area.

3. Results

In order to update and adjust the main design characteristics, design requirements and recommendations related to the design of cellular concrete products, taking into account the current state of the production base and construction practice, MS standards of organizations are developed, which are generalized requirements and recommendations of modern regulatory documents, as well as experience gained in recent years both in Russia and abroad in the field of design of cellular concrete products.

The most frequently applied standards for the construction of structures made of autoclaved cellular concrete products are the standards of the National Association of autoclaved cellular concrete manufacturers (MS NAAG) and the National Association of builders (MS NOSTROY).

Rules for the design and construction of MS NAAG 3.1-2013, developed by a non-profit organization that represents more than half of the Russian cellular concrete market – the National Association of autoclaved cellular concrete manufacturers, which unites more than a dozen of the largest modern manufacturing enterprises in terms of their capacities, including such as JSC Bonolit-Construction solutions, LLC Eco, CJSC Interegional Production and Resource Corporation GRAS, LLC KSKM, LLC LSR. Cellular concrete, JSC Kcella-Airblock-Center and others. This standard provides guidance on the use of non-reinforced products and basic information on the use of reinforced bar lintels and panels, as well as recommendations for basic structural solutions [10].

Edition of MS NOSTROY 2.9.136-2013 is a standard for device structures with the use of goods and reinforced elements of cellular concrete autoclaved National Association of builders with its scope and partition wall blocks and panels, large unreinforced blocks and reinforced elements, such as blocks, load-bearing and curtain panels for exterior walls and load-bearing panels of the inner walls, panels and floor coverings, bearing and non-bearing lintel, and containing in the appendices guidelines for the design of structures made of reinforced products made of autoclaved cellular concrete, which are of a recommendatory nature [12].

It should be noted that in all national and European normative documents focused on the design and construction of walls made of small cellular concrete wall materials, the issues of reinforcement of masonry, the technical solutions of constructions and nodes of their mates with adjacent components, while the requirements to porous concrete structures, working on the curve, represented insufficiently. At the same time, the production of bendable reinforced products, which accounts for almost 1% of the total volume of cellular structures produced in the Russian market, which is mainly focused on the production of small-piece wall materials, is not of interest for large-scale research.

![Figure 1. Structure of national production of cellular concrete products in 2012-2018.](image-url)
As a result, leading manufacturers of bent cellular concrete structures need to develop their own standards for technical regulation of product quality. Thus, table 1 shows the author’s analysis of the abundance of regulatory documents developed by leading Russian residents of the National Association of autoclaved aerated concrete manufacturers for their products on the example of an extensive range of various brands of reinforced cellular concrete jumpers, with an average density of D500 and a compressive strength class of at least B2.5, corresponding to all current national technological standards and requirements, and for individual manufacturers even European quality standards [2, 4].

Table 1. Nomenclature of manufactured lintels.

| Manufacturer | Conditional Marking | Concrete | Reinforcement | Normative document |
|--------------|---------------------|----------|---------------|--------------------|
| LLC DSK GRAS| PRS B2.5 B3.5      |          | B500C Bp-I    | TC 5828-001-82651425-2014 |
| LLC LSR. Wall LLC ECO | BPA B3.5 | AIII (A400) A500C B500C Bp-I A240 | MS 5741-003-1522473-2016 TC 5828-009-67236060-2015 |
| CJSC Kcella-Airblock TM “YTONG” | PN B2.5 B3.5 | B500C | MS 73045594-004-2016 |
| JSC BONOLIT-CONSTRUCTION SOLUTIONS; PB PORITEP | BPA B3.5 | A400 A240 AIII A500C B500C Bp-I | TC 5828-009-67236060-2015 TC 23.61.12.127-011-67236060-2018 |
| CC AeroBel TM PORITEP | PG B2.5 | | TC 5828-002-98818904-2016 |
| LLC Glavstroy Ust-Labinsk JSC | PB B3.5 | A400 A240 | MS 39136230-02-2018 MS-39136230-2008 |
| Glavnovosibirskstr oy Plant “Sibit” | | | |

However, it is worth noting that the potential of standards developed by manufacturers taking into account the current state of capacities, current construction practices, as well as the critical analysis of numerous tests of reinforced cellular concrete structures, which contributes to a wider and correct application of cellular concrete structures on the Russian market, cannot be fully used by designers, as updated building codes and current codes of rules have priority, because they are official regulatory documents, mandatory for universal application, while the standards of organizations and technical specifications developed by manufacturers are only recommendations.

Successful and complete standardization of reinforced concrete elements, meanwhile, is obviously a derivative of the reliability, efficiency and prevalence of technical solutions used in its production, which are sufficiently deeply and fully justified by scientific research and production experience in the field of theory of operation and management of cellular concrete properties, which, alas, cannot be said about reinforcement products represented by traditional rods and frames, currently only partially adapted to use in cellular materials from the practice of reinforcing heavy concrete.
After analyzing the working drawings of the mass-produced bent cellular concrete products on the Russian market – bar lintels, we can conclude that all structures are the same type of traditional structural solutions of a porous array of cellular concrete reinforced with flat and three-dimensional reinforcement frames. Reinforcement of elements represents the following design decision: the placement of the joints concreting of the steel rods with subsequent grouting with concrete.

The author proposes to optimize design solutions when choosing a method for reinforcing cellular concrete bent structures by changing the design scheme and the principal approach to the perception, transmission and distribution of internal forces in the cellular concrete by studying and implementation of an innovative reinforcement product – a steel cogged tape (SCT, Fig. 2) [2]. The tape is a thin plate with a figured open perforation, the geometric dimensions and location of which are the subject of structural calculation depending on the physical, mechanical and deforming properties of cellular concrete and the accepted theory of strength of the contact layer of elements.

![Figure 2](image)

**Figure 2.** Structural options of SCT for cellular concrete bent elements: 90-degree cogged and 180-degree cogged.

The SCT is made of stainless steel with a yield strength of up to 300 MPa, and has a controlled side surface that most fully implements the principle of contact interaction of discrete reinforcement and cellular concrete surrounding array, which is the distribution and transmission of contact forces through a combination of tangential and normal stresses, the specific weights of which are determined by the SCT topology, selected according to general calculation algorithms for specified reinforcing materials and concrete. Practically significant for the purpose of proper codification of SCT cogged parameters and methodologically simple for the best formalization of calculation algorithms, the authors consider the convolution of the geometric parameters of the SCT cogged into a single indicator “SCT parameter”, which functionally connects the key geometric characteristics of the element – the length, width, thickness of the plate, the angle of rotation of the cog (see Fig. 2). Numerical studies of information models of cellular concrete beams carried out by the authors (Fig. 3) demonstrated an expressed dependence of the calculated normal and tangential components of integral stresses in the contact zone (see Fig. 2). The unevenness index (deviation of the maximum from the average stress level), which determines the presence and distribution of stress concentrators and zones of potential destruction of the contact layer until the design bearing capacity of the object is reached (reinforcement pulling), is up to 40%, being leveled completely within the value of the SCT parameter 0.4-0.5, which allows evaluating this parameter’s margins as a closest to optimal.
The main costs of manufacturing PC-beams

| Costs                                      | Rubles |
|--------------------------------------------|--------|
| The main costs of manufacturing PC-beams   | 85     |
| PC V2.5                                    | 50%    |
| Total                                      | 128    |
| Additional costs of SGB                    | 20     |
| SGB                                        | 50%    |
| Total                                      | 158    |
| Increase in production costs               | 19%    |
| Increased load-bearing capacity            | 50%    |

Figure 3. Experimental cellular concrete bent structure analyzed in a numerical experiment to evaluate the efficiency of using a dispersed reinforcement element of the SCT.

Thus, author’s proposal for use in the practice of discrete reinforcement of bent cellular concrete structures, that still retains significant unused bearing capacity with the regular rebars due to the insufficient contacting, offers innovative steel reinforcing element SCT with a side surface, better adapted to real working conditions of reinforcement in cellular concrete, as well as a high degree of controllability of the reinforcement efficiency by both normal and tangential stresses with the possibility of varying the specific weight of stresses in the integral contact resistance.

4. Discussion

The use of the innovative reinforcement product proposed by the author for cellular concrete structures in practice becomes possible only after technical regulation of the procedures for its selection, evaluation and calculation, which requires a detailed study of the actual operation of the reinforced bent structures under load, modelling their stress-strain states and developing an engineering applied methodology for selecting structural parameters of SCT that determine its cost and rationality.

5. Summary

Due to the abundance of regulatory documents for design of concrete and reinforced concrete structures and partially inconsistent requirements for reinforced products and structures from cellular concrete, there is a reasonable doubt about the admissibility of the application of the estimated requirements of certain normative documents in the design of bearing and enclosing reinforced cellular concrete structures for the purposes of the compliance characteristics of individual load-bearing and enclosing structures made of cellular concrete, as well as buildings and structures in general, the requirements of technical regulations on the safety of buildings and structures [11]. In this regard, there is a need to revise and systematize existing Russian and European standards that contain requirements for the design of directly reinforced structures made of cellular concrete, generalize data and update information in them, as well as develop modern national standards in this area in order to update the main design characteristics, specify design requirements and recommendations for the design of reliable and durable structures made of cellular concrete, they allow to improve the quality of manufactured construction products and increase the safety of buildings and structures with load-bearing and enclosing structures made of cellular concrete [6]. At the same time, the prospects for updating technical regulations in the design of reinforced cellular concrete structures are highlighted by the great potential for optimizing traditional discrete reinforcement products adopted in current practice, which prevent the implementation of rational design principles in this promising technology for the growth and development of resource-efficient and energy-efficient individual housing construction.

Directions for improving the design principles and technical design solutions for bent cellular concrete structures also include improving the design of their reinforcement, which implements the expanded capabilities of complex contact resistance and the significant potential of the load-bearing...
capacity of elements by more fully including the material of the reinforcement element in the work. The author’s proposal in this matter is to develop structural design, design methodology, and applied engineering methods for calculating the innovative steel reinforcement discrete element of cellular concrete bent structures — SCT of controlled topology. Keeping the general principles of the computation algorithms and embedding the SCT in the cross-section of bent beams, provided the regulatory requirements of technical regulations, it’s possible to enable up to 50% better use of the actual strength of the steel reinforcement to provide a suitable for mass use the plastic destruction of reinforced cellular concrete construction to ensure greater structural safety and performance of rebar in concrete and as a consequence, lower total cost of ownership of structures and the building made up of them by increasing the term, reducing the cost of maintenance and increasing of structural reliability [1]. Overall, the implementation of the proposed measures for the improvement of tools of technical regulation for designing of cellular concrete bending elements, with a proposal of use in practice and ensuring regulatory technique for the development of innovative reinforcing elements with controlled contact resistance, will in the short term allow to identify and implement potential additional resource efficiency and reduce the capital intensity of owning real estate property complexes constructed in reinforced cellular concrete structures.

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