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OPTIMIZATION OF THE GEOMETRIC PARAMETERS OF THE CROSS-SECTION OF A HOLLOW-CORE FLOOR SLAB TO CREATE A RANGE OF PRODUCTS MANUFACTURED USING THE FORMLESS MOLDING TECHNOLOGY AND INTENDED FOR CONSTRUCTION IN SEISMIC REGIONS

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ABSTRACT
For the possibility of using in the construction of seismic regions of hollow-core slabs without formwork, reinforced with prestressed high-strength wire reinforcement, the problem is solved to determine the optimal combination of geometric parameters of the cross-section of the geometric parameters of the cross-section of such a slab while observing the normalized operational requirements and restrictions of the norms of seismic-resistant construction As a result of the research, a constructive solution for the cross-section of the slab was developed for the maximum values of the parameters specified by the customer - span, operating load. A utility model patent was obtained for the proposed structural solution of the slab section.

Keywords: hollow-core slab without formwork, optimization, height, parameters of cross-sectional configuration, strength.

INTRODUCTION
The management of the Uzbek-Russian joint venture The BINOKOR TEMIR-BETON SERVIS joint venture invited the specialists of the Tashkent Institute of Architecture and Civil Engineering to develop a project “Creation of a range of products from prestressed hollow-core slabs without formwork molding under, unified loads 4,5; 6.0 and 8 kN/m^2, having a length of 4.7; 5.9; 6.2 and 7.2 m, width 1.2 m”. Slabs are intended for use in residential, public and industrial buildings (up to 7 floors) with load-bearing walls of a complex structure of brickwork, reinforced with reinforced concrete inclusions), reinforced concrete frame and panel systems during their construction in areas with seismic intensity of 7 and 8 points. Here, the issue of optimizing the consumption of high-strength wire reinforcement for slabs imported for the country should be resolved, and the minimum concrete strength (no more than B30 class) should be determined, at which it would be possible to exclude the use of transverse reinforcement and the need to strengthen the support sections of the slabs. In this regard, since February 2018, innovative research has been carried out on the introduction of prestressed hollow-core slabs of stand-off formwork on an industrial scale in Uzbekistan.

THE MAIN FINDINGS AND RESULTS
In recent years, many enterprises for the production of precast concrete have been modernized in Uzbekistan with the use of modern equipment of non-formwork continuous molding technology (from Italy, Spain, Russia) of structures on long stands up to 120 m. Reinforced concrete structures produced at enterprises using in-line molding technology cannot meet the construction demand for quality and prices for the products of these enterprises [1].
The production of prestressed floor slabs without formwork allows the creation of a wide range of products [2, 3], increasing the possibilities of their use in various structural residential systems; public and industrial buildings. The big advantage of this technology is the ability to produce slabs of any required length from a single pre-stressed sheet by a cutting machine with a circular saw. Until now, the design, production and application of hollow-core slabs without formwork in construction have been little studied, which causes problems in the use of new technological lines for the production of products and their industrial application in construction [1, 4, 5], especially in seismic regions [6, 7].
The aggregate-flow method of production of hollow-core slabs is limited to the production of products with a length of no more than 7.2 m with their high metal consumption. For the manufacture of one running meter of a product produced by the formless molding method, 2.5 times less metal is required compared to

the aggregate-flow method, due to the absence of: embedded parts, transverse reinforcement, horizontal meshes in the shelves and indirect reinforcement at the ends of the slab, outlets fittings [1, 8, 9].

The design features of slabs without formwork do not meet the requirements of Uzbekistan standards KMK 2.03.01-96 “Concrete and reinforced concrete structures". In the Russian Federation (and in other CIS countries - author's note) there is no normative document that would regulate the design of hollow-core slabs without formwork, except for the standard of Belarus STB EN 1168-2012 “Prefabricated reinforced concrete products”. Hollow-core slabs, which provides recommendations for the design of such slabs. But it is problematic to use the methodology given in this standard for calculating hollow-core slabs without flange molding because of the difference between this method and the corresponding national norms of Uzbekistan (and Russian norms SP 63.13330.2012 “Concrete and reinforced concrete structures”), since STB EN 1168-2012 is not adapted to these regulatory documents and the content repeats the European standards EN 1168-2012 [6, 10].

To achieve the goal of the project, the initial task was set to determine the optimal parameters of the cross-section of a hollow-core slab, taking into account the above-mentioned conditions and customer requirements.

REQUIREMENTS, LIMITATIONS AND CHOICE OF PARAMETERS FOR OPTIMIZATION

It is known that one of the most important problems in the development of reinforced concrete structures is to increase the span of the structure while minimizing the size of its cross section. In connection with this problem and others, the following is stated in [4]: “Creation of new and development of existing methods for calculating concrete and reinforced concrete structures, providing the necessary reliability and durability, is the basis for the development of modern design solutions for buildings and structures that reduce the labor intensity of construction and allow obtaining maximum economy of materials”. Thus, designers who want to implement an individual project cannot be content with existing approaches to the calculation of reinforced concrete structures based on a variety of design solutions that differ from the standard ones, for example, in the configuration of the cross-section of the structure. In this regard, the parameters of the slab section were assigned based on the following basic requirements:

- Ensuring the required strength, crack resistance and rigidity of the structure;
- The manufacture of the structure should be versatile and technologically advanced.

The factor of universality of hollow-core slabs without formwork is the possibility of using them in buildings with various structural systems: frame, large-panel, with bearing walls made of brickwork, etc., with different values of loads and spans. From the standpoint of innovative implementation of the considered slabs, manufacturability is the ability to produce slabs in an industrial volume with transformed geometric parameters that do not worsen their strength and stiffness parameters on modern equipment (stand-off mold lines).

The choice of the optimal parameters of reinforced concrete structures is a multi-criteria task. In this regard, based on experience, a comparatively simple objective function that lends itself to analysis is set. As the target function, the following can be selected: consumption of materials, duration of construction, estimated cost, etc., taking into account the requirements for ensuring the strength and serviceability of individual elements and the building as a whole.

Very often, the criterion for the optimality of reinforced concrete structures is the minimum weight of the structure, since it is the own weight of the structure that has a significant impact on the cost of construction. Another criterion for assessing the effectiveness of reinforced concrete structures is to reduce the consumption of reinforcing steel.

It is known from experience in designing hollow-core slabs for non-seismic areas that the voidness of the slabs varies from 40 to 55%. With an increase in the hollowness of the slabs, the bearing capacity of the slabs along the normal sections is significantly reduced due to the transition of the neutral line to the inter-void partitions (ribs) of the slab, and the strength along the inclined sections on the supporting sections of the slabs also decreases. In addition, the deformability of the slabs increases, i.e., its rigidity decreases.

Thus, the task was concretized - finding the optimal combination of height and configuration parameters of the cross-section of a hollow-core slab without formwork, while observing normalized operational requirements.

The main variable parameters are the height and degree of voidness of the section, characterized by the size and shape of the voids.

The following requirements and restrictions of the norms of earthquake-resistant construction of Uzbekistan (KMK 2.01.03-96 “Construction in seismic regions”) and Russia (SP 14.13330.2014. Code of rules. Construction in seismic regions) were taken into account:

1. When calculating the strength of bending elements reinforced with high-strength wire of class Bp1400, an additional factor of operating conditions is introduced, equal to 1.1.

2. The boundary relative height of concrete of the compressed zone of the section of bending elements equal to $\xi_R = x_R/h_0$ ($x_R -$ is the boundary absolute height of the compressed zone of the section; $h_0 -$ is the working height of the section) is taken with multiplication by a factor of 0.7 at the design seismicity of the construction site of 8 points.

It should be said that the value ξ_R according to the above-mentioned norms of Russia is adopted differentially depending on the calculated seismicity of the construction site: 0,5ξ_R- for a site with a seismic impact intensity of 9 points; 0,7 ξ_R - for a site with seismicity of 8 points; 0,85ξ_R for a site with a seismicity of 7 points. According to the norms of the Republic of Uzbekistan [5], the value ξ_R is taken by multiplying by an integrated coefficient equal to 0.85 for sites with seismic intensity of 7, 8, 9 points. Thus, taking ξ_R with a factor of 0.7 provided for by the requirements of the RF standards, the calculated structure has increased initial characteristics, "excluding any damage or disruption to serviceability associated with the use of harm to life or health of people, property, and the environment”.

THEORETICAL BASIS FOR CALCULATION

For the design section of hollow-core slabs when calculating according to the first group of limiting states (in terms of strength), traditionally, but reasonably, the section of the slab is taken, reduced to an equivalent double-T section (Fig. 1). The pre-stressed reinforcement is located in the rib of the reduced section at the level of the lower flange. The overhangs of the lower flange are not included in the calculation - all efforts in the stretched zone are transferred to the reinforcement.

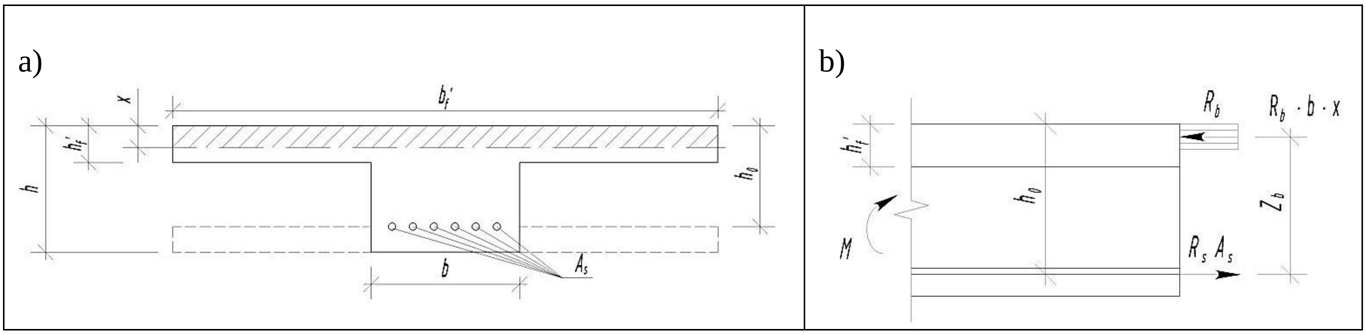

Figure 1. Design section (a), diagram of forces and stress diagram in section (b) of the slab when calculating its strength

Hollow-core slabs without formwork should be designed so that, in the calculation, the boundary of the compressed zone passes in the upper flange, i.e. condition

$$R_s A_s \leq R_b \cdot b_f{}' h_f{}' \qquad (1)$$

is met.

This is due to the fact, as noted above, with a sharp decrease in the strength of the slab along inclined sections and an increase in its deformability, when the boundary of the compressed zone passes into the edge of the reduced section of the slab.

The bending moments taken by the concrete in the compressed zone M_{bu} and tensile reinforcement M_{su} are determined by

$$M_{bu} = R_b \cdot b_f{}' \cdot x \cdot Z_b; \qquad (2)$$

$$M_{su} = R_s \cdot A_s \cdot Z_b, \qquad (3)$$

where R_b and R_s – design resistance of concrete to compression and tensile reinforcement;

A_s − the calculated cross-sectional area of the reinforcement located in the tensile zone of the section of the element;

$b_f{}'$ − width of the upper section flange;

b − rib width of the reduced section;

h_0 − working section height;

x −the height of the compressed area of the section.

$Z_b = h_0 - 0{,}5x$ − shoulder of the internal pair of forces (the distance between the resultant forces in the compressed zone of concrete and tensile reinforcement).

From expressions (2, 3), it can be noted that with a decrease in the section height *"h"*, the value Z_b decreases, which leads to a decrease in the bearing capacity of the slab. It also follows that the bearing capacity decreases in proportion to the decrease in the height "h", provided that the height of the compressed zone of the section $x = const$, ie, provided that the resultant forces in the concrete of the compressed zone $R_b \cdot b_f{}' \cdot x$ and reinforcement $R_s \cdot A_s$ remain unchanged.

If we take the parameter of voidness V_ϑ/V constant (V_ϑ − is the volume of voids at the length of 1 m of the slab; V − is the volume of the slab at its length 1 m), then with an increase in the height of the section h, the weight of the slab increases. Given this regularity, it is possible to determine the maximum bending moment from an external load q

$$M = \frac{[q + \gamma_b(V - V_\vartheta)] \cdot {l_0}^2}{8}, \quad (4)$$

where γ_b − is the volumetric weight of reinforced concrete;

l_0 − - calculated span of the slab.

Let us denote the ratio Z_b/h through φ, then the shoulder of the internal pair of forces is $Z_b = \varphi \cdot h$.

If we substitute expression $Z_b = \varphi \cdot h$ into formula (3) and solve together with equation (4), we obtain a dependence for the section height, taking into account the voidness of

$$h = \frac{q + \gamma_b(V - V_\vartheta)}{8\, R_s \cdot A_s \cdot \varphi/{l_0}^2} \quad (5)$$

V. RESULTS

In the calculations, the voidness of $V_\vartheta/V = 0{,}5$ typical hollow-core slabs with a height of 220 mm and a width of 1.2 m, produced using aggregate-flow technology, was taken as a basic option.

Substituting into formula (5) the varied values of the height of the section of the slab h (220, 210, 200, 190 and 180 mm) at constant values of voidness V_ϑ/V (0.5; 0.45; 0.4; 0.35), we obtained the values of the external loads that the slab is capable of taking (table).

Table. The greatest load (including its own weight), taken by the slab, at different cross-section heights and given values of voidness

Plate height, mm	**Load taken by the plate, kN / m^2 with emptiness, V_ϑ/V**			
	0,5	**0,45**	**0,4**	**0,35**
220	16,43	16,71	16,98	17,24
210	15,40	15,66	15,92	16,17
200	14,39	14,63	14,88	15,13
190	13,37	13,60	13,83	14,07
180	12,36	12,58	12,80	13,02

JUSTIFICATION OF THE PRACTICAL SIGNIFICANCE OF THE RESULTS

According to the results of calculations, the cross-section of a slab with a height of 190 mm and a voidness of 38% is accepted, i.e. the strength of a slab with such a cross-section with an estimated span of 7.04 m and an action on the slab with a calculated unified load of 8.0 kN / m2 is ensured.

The geometry and design of the slab section is shown in Fig. 2.

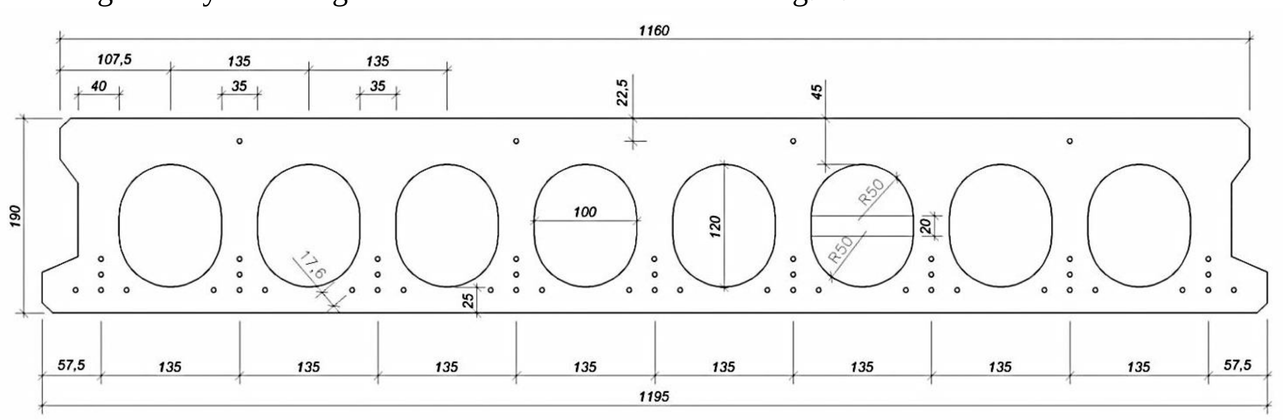

Fig. 2. Structural section of the slab

Taking into account the above-mentioned requirements of the regulatory documents of Uzbekistan and Russia in the calculation led to an increase in the height of the upper flange in relation to the height of the lower flange of the slab section, i.e., the voids in the slab were located asymmetrically.

The height of the upper thickened shelf (in comparison with the height of the lower shelf) of the reduced section of the slab (Fig.) Is 0.27 h, the height of the lower shelf is 0.17 h. The asymmetric arrangement of voids in the slab cross-section allows an increase in the moment of inertia and the moment of resistance of the entire cross-section and contributes to an increase in crack resistance and stiffness of the slab.

The reduced (total) thickness of all ribs *"b"* is 0.32 b_f'. The reduced height of the concrete cross-sectional area, reduced to the solid rectangular section of the slab, is 118 mm.

CONCLUSION

1. The configuration of the slab section shown in Fig. 2 is adopted for the entire product range under consideration, noted in section I. Introduction.
2. A patent for a useful model was obtained for the proposed constructive solution of the cross-section of a hollow-core floor slab of stand-off formwork, intended for construction in seismic regions [12].
3. To date, the following tasks have also been resolved to achieve the goal of overflight:

• Control tests to assess the bearing capacity, stiffness and crack resistance of the proposed slabs from a pilot batch of products manufactured on a formless molding line; design documentation and technical specifications for the production of plates according to the considered nomenclature were developed;
• Developed anti-seismic connections of the proposed slab with adjacent structures in the building floor;
• A slinging assembly was developed, embedded in the hollows of the slab, without the use of a slinging (mounting) loop.

Based on the results of the aforementioned developments, articles are being prepared for publication.

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