Design features of low-rise buildings walls erected from permanent formwork ComBlock units

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Abstract. The study focuses on the design of load-bearing monolithic concrete and reinforced concrete walls of low-rise buildings erected from permanent formwork ComBlock units for construction, in areas without episodic influences and analysis of their work. While developing the recommendations the main attention was paid to working out design solutions of load-bearing monolithic walls with minimal reinforcement consumption. The guidelines contain general provisions for the design and calculation of load-bearing vertical elements of a house; numerous studies of the stress-strain state of monolithic vertical load-bearing elements of low-rise buildings with different structural schemes.

1. Introduction

Nowadays, a tendency of expanding construction of individual low-rise housing takes place in many countries including Ukraine. Structural elements of monolithic concrete and reinforced concrete are often used in their design and construction. Buildings with energy-saving exterior walls have become of great demand. Modern construction technologies are aimed at simplifying and accelerating the construction process.

One of the possible ways to solve these problems is to use permanent formwork with high thermal insulation properties for the construction of such buildings. Kharkiv building and production company AVcom is engaged in the construction of such houses with ultra-low energy consumption with the aid of the permanent formwork ComBlock.

The increase of economic efficiency of these structures is related to the reducing of their metal content.

The load-bearing vertical structures of low-rise buildings with a rigid structural scheme feature relatively small vertical stresses in the concrete walls provided tensile forces. They do not exceed the tensile strength of concrete. Hence, the installation of assumed reinforcement is not necessary. Furthermore, the objective of minimization of used constructive reinforcement becomes of current relevance.

The problem of developing design solutions and methods of calculating the load-bearing structures of the above-mentioned buildings with minimum consumption of steel reinforcement has been solved within this study.
2. Analysis of recent research and publications

Permanent formwork is special units fabricated from different materials. This technology cardinally simplifies the process of monolithic construction, and the building itself does not require additional insulation. There are several known variants of this type of formwork, which use slabs of fibre mat, wood fibre concrete, cement-bonded chipboards or other materials, in which cement is comprised as a component.

Energy-efficient wood fibre concrete blocks of permanent formwork have become widespread, namely: BRISOLIT (Germany, 1934), DURISOL (Switzerland, 1932), TECOLIT (Russia, 2014). Wood chips are used for their manufacture. They are mixed in certain proportions with cement and mineral additives, and expanded polystyrene or PIR (polyisocyanurate) [1, 2, 3]. In 1956, the family company VELOX WERK patented a similar technology of monolithic construction in permanent formwork of VELOX chipboards [1] in Austria. The system fully corresponds to all modern standards, consumer requirements and has a fairly high competitiveness.

In the sixties of the last century, the Austrian engineer proposed to make a permanent formwork from expanded polystyrene in the form of hollow blocks. It is possible to make a wall like from children's bricks, and then to fill in internal cavities with concrete. After the concrete hardens, a wall in the form of a sandwich consisting of concrete, dressed in a heat-insulating "shirt" of expanded polystyrene, is obtained. Such a wall requires additional insulation no longer. Since the invention of expanded polystyrene blocks of permanent formwork have constantly been modernized, introduced into production by various companies in many countries: PLASTBAU (Switzerland) [1]; Ecostone (Finland); IntegraSpec (Canada) [4]; Isodome (Poland) [5, 6]; Plastbau and Thermoblock (Ukraine) and others [7, 8].

Insulating concrete formwork industry continues to strive for improvement and creates exceptionally energy-efficient, firm and environmentally friendly structures due to many years’ experience and innovation.

The analysis of the existing similar permanent formworks and technologies has proved that there are no unified regulatory documents for designing houses with their aid. Therefore, it became necessary to develop methods of calculating and designing the walls of low-rise buildings erected from blocks of permanent formwork ComBlock.

3. Results of theoretical studies

Kharkiv building and production company AVcom is engaged in the manufacture of permanent formwork ComBlock units with adjustable width of the concrete core of the wall (Figure 1). This unit consists of a panel of external insulation (thickness from 50 to 300 mm) and an internal gypsum panel (which does not require further plastering) (Figure 1, a) or a removable inner panel of the formwork (Figure 1, 2).

Figure 1. ComBlock with gypsum panel (a) and with removable formwork panel (b)
The panels are interconnected by adjustable plastic screeds (jumpers), which allow changing the thickness of the core of the wall in the range from 100 to 430 mm [9]. Walls built with ComBlock have significant advantages over walls made of other materials, for example, cheaper than brick - by 30%, aerated concrete - by 10%; they are more environmentally friendly and fireproof than walls made of thermo blocks.

After the abolition of state building codes DBN V.2.6-6-95 in 2015, which specified the standards for the design, construction and operation of the construction system "Plastbau" (similar to ComBlock), no regulatory framework exists currently in Ukraine. The need for developing guidelines for the design of buildings using permanent formwork ComBlock is especially important. The need is relevant under the conditions of the introduction of new regulations DBN V.2.6-98:2009 (National Building Standards) and DSTU B V.2.6-156:2010 (National Standards of Ukraine) for the design of heavy concrete and reinforced concrete structures developed on the basis of Eurocode 2 EN 1992-1-1:2004 in our country.

The authors performed numerous studies of the stress-strain state of load-bearing vertical elements using permanent formwork ComBlock units. There were developed recommendations for the design of load-bearing concrete and reinforced concrete structures of frameless (wall) and frame-wall monolithic residential buildings up to 5 floors for construction in areas with normal soil conditions in non-seismic areas.

3.1. Basic design requirements
It is known that the load-bearing structures are calculated for the first and second groups of limit states, taking into account the most unfavourable combination of loads. As a rule, the deformation (stiffness) characteristics of reinforced concrete elements are taken on the basis of methods that consider the nonlinear operation of structural materials, when determining the forces in the load-bearing elements of structures and horizontal displacements of the system.

The values of nonlinear stiffness of reinforced concrete elements are taken depending on the stage of design, calculation requirements and the nature of the stress-strain state of the element. The calculation of the structural system is performed for all successive stages of construction (in case of a significant change in the design situation) and for the stage of operation. At the first stage of calculation of the structural system, whereas reinforcement of concrete elements is unknown, the nonlinear operation of the elements should be estimated by reducing their stiffness by means of hypothetical generalized coefficients or using a "fictitious" modulus of concrete deformation. At the following stages of calculation of the structural system, when the installation of reinforced concrete elements is known, the specified values of elements stiffness are introduced into the calculation. These values are determined taking into account reinforcement, crack formation and development of inelastic deformations in concrete and reinforcement according to DBN V.2.6-98:2009 and DSTU B V.2.6-156:2010.

At the first stage of calculation, it is allowed to take approximate values of the elements stiffness in order to estimate the forces in the elements of the structural system. It is taken into account that the distribution of forces in the elements of structural systems depends not on the value but mainly on the stiffness ratio of these elements. It is recommended to take the specified values of stiffness in accordance with DSTU B V.2.6-156:2010 for more accurate assessment of the distribution of forces in the elements of the structural system. A significant reduction in stiffness in the bending plate elements (because of the possible formation of cracks) should be considered in comparison with the eccentrically compressed elements. At the first approximation, it is advisable to take the modulus of elasticity of concrete $E_c$, which is equal to its calculated value in accordance with table 3.1 of DSTU B V.2.6-156:2010.

At the following stages of calculation at known reinforcement, the specified stiffness of elements is accepted taking into account reinforcement, existence of cracks and inelastic deformations in concrete and reinforcement. The values are defined according to the operating regulatory documents.

In addition, it is recommended to accept rational constructive parameters of walls, which are established on the basis of the technical and economic analysis when designing. For low-rise buildings with permanent formwork ComBlock the advisable thickness of monolithic walls should not be less
than 150 mm, concrete class - not less than C15/16, the amount of reinforcement - in accordance with DSTU B V.2.6-156:2010.

3.2. Calculation and construction features of buildings with bearing concrete walls

The calculation of bearing capacity of concrete elements under the action of longitudinal compressive force and bending moment should be performed for sections that are normal to their longitudinal axis.

In general case, the calculation of the reinforced concrete structure is performed on the basis of diagrams of concrete and reinforcement deformation and nonlinear deformation model. It is allowed to perform the calculation of concrete elements by the simplified method. In this case, the ultimate deformations of stretched concrete are used as a criterion for failure. The use of simplified diagrams of "stress-strain" dependence is possible if they are equivalent or more conservative than those given in paragraph 3.1.4.1 DBN V.2.6-98:2009.

Concrete elements are calculated according to the ultimate forces, which are determined on the basis of the following preconditions: the sections after deformation remain flat; equations describing a complete diagram of concrete deformation are considered valid. It is allowed to use a two-line diagram of concrete deformation with a limited length of the horizontal branch; the largest elongation of the extreme stretched fibre equals $-2f_{ctm}/E_{ck}$.

The influence of longitudinal bending and random eccentricities should be taken into account, when calculating the eccentrically compressed concrete elements.

As for the walls made in compliance with the corresponding construction and care regulations, temperature and shrinkage deformations can be neglected. In the absence of measures to prevent tensile fracture of cross section, it is necessary to limit the maximum eccentricity of the force application in the section in order to avoid the formation of large cracks.

Numerous researches of a stress-strain condition of bearing and self-bearing walls from permanent formwork ComBlock units of various constructive schemes have been performed on the basis of the offered various architectural and design solutions of buildings. Gradual calculation of load-bearing walls (columns) of buildings has been done using software complexes LIRA-SAPR and MONOMAKH-SAPR.

3.3. Numerical studies of stress-strain state of walls of low-rise buildings erected from blocks of permanent formwork ComBlock

Estimated schemes of frameless buildings are classified [10]: by the design nature of spatial work - in to one-, two- and three-dimensional; by the type of unknowns - into discrete, discrete-continuum and continuum; by the type of construction, which is the basis of the calculation scheme – into rod, plate, combined ones.

The forces acting in the wall structures and floors should be determined on the basis of spatial calculation schemes. In this regard, the nature of external loads application, the characteristics of calculated system, and the required accuracy of the calculation ought to be taken into account. Spatial calculation schemes allow to determine the forces in the structures and their displacement from external loads in any direction. The three-dimensional calculation scheme takes into account the peculiarities of the interaction of load-bearing structures most accurately, but the calculation based on it is the most complex.

Discrete computational models based on mathematical and geometric sampling of spatial structures calculated by the finite element method (FEM) became the most widespread. Sampling parameters and types of finite elements are accepted with regarding the requirements for the accuracy of the model reproduction of the real structure.

The spatial structural system is a statically indeterminate system. Sampling of structural schemes is advisable to perform with the aid of shell and rod finite elements used in the calculation complex.

When constructing a finite-element calculation model, the dimensions and configuration of finite elements are assigned on the basis of the possibilities of the specific calculation programs used. They are accepted so that the required accuracy in determining forces applied to the length of columns and
area of floor slabs, foundations and walls should be provided. Here with, the total number of finite elements in the calculation scheme, which affects the duration of the calculation, is taken into account.

The calculation of structural systems by the finite element method is generally performed using special certified computer systems. The requirements of DBN V.2.6-98:2009 and DSTU V.2.6-156:2010 as for physical and geometric nonlinearity and second-order influences are implemented in these systems. Such a system is LIRA-SAPR. To simplify and accelerate the creation of the calculation scheme, it can be used the software package MONOMAKH-SAPR. The automated breakdown into finite elements is carried out in this software package when choosing the size and configuration of the elements (Figure 2).

![Figure 2. General view of spatial calculation models in PC MONOMAKH-SAPR (a) and calculation scheme of walls in finite elements (b) in PC LIRA-SAPR](image)

At the first stage of calculation, it is recommended to take the modulus of elasticity of concrete $E_{cd}$, which is equal to its calculated value in accordance with table 3.1 DBN V.2.6-98:2009 in order to estimate the forces in the elements of the structural system.

Generally, the calculation of the load-bearing capacity of the walls can be performed as flat selected elements on the combined applying of normal and shear forces, bending moments, torques, and transverse forces applied on the sides of a flat selected element. The forces are obtained from the calculation of a structural force by means of the finite element method according to DSTU-NB V.2.6-205:2015.

The calculation from the surface of the wall is performed similarly to the calculation of flat floor slabs, determining the values of the ultimate bending moments taking into account the influence of normal forces.

According to the results of the calculation, an image of the deformed scheme is formed (Figure 3, a). The construction of is fields of displacements (Figure 3, b) and stresses for wall elements is performed.

At the next stages of calculation, the specified stiffness of plates is accepted with reinforcement, existence of cracks and inelastic deformations in concrete and reinforcement in mind, provided the known reinforcement. All the parameters are defined according to the statutory regulatory documents.

In this case, the calculation of the walls will be carried out by dividing the flat element into separate layers (upper, middle and lower) with the definition of the main stresses on each layer separately and the identified elements, in which cracks were formed.
The calculation with account of the inelastic deformations and real diagrams of concrete deformation (considering the physical nonlinearity) will allow to determine the location and direction of cracks formation, and perform, if situation so requires, the necessary reinforcement (Figure 4). The diagram of the concrete state can be specified in the form of complete or simplified one according to the class of concrete in compliance with item 3.1.4 DBN V.2.6-98:2009.

After determining the forces in the cross sections of the walls, it is necessary to check the bearing capacity of dangerous concrete sections according to the method described in paragraph 2.2.1
DBN V.2.6-98:2009. If the load-bearing capacity of the section is not provided, it is necessary to continue the calculation in the PC LIRA-SAPR in ARM-SAPR with the determination of the number of longitudinal and transverse reinforcement of the walls.

There is a redistribution of forces in monolithic reinforced concrete. The height of the jumper has an unlimited height from the top of the opening to the bottom of the next slot located above it. The reinforcement of the wall can be taken into account thereby.

The calculation of jumpers can be performed as for a wall beam (Figure 5, a) or a beam with clamped supports (Figure 5, b). If there is a small distance from the top of the slot to the bottom of the floor, and the wall is more like a jumper in this place, then it should be reinforced as a jumper (Figure 6). If there is a significant distance from the top of the opening to the top of the wall, the opening must be framed with clamps. When reinforcing the jumper its cross-sectional height can be considered of 300 mm or less.

**Figure 5.** The cross-section area of reinforcement: a - by 1 LM near one surface on the X axis (horizontal); b - percentage of reinforcement

**Figure 6.** Calculation of jumpers: a - nature of bending moments diagram; b - percentage of reinforcement
For monolithic concrete walls, a calculation scheme with hidden columns and crossbars can also be used (Figure 7), where monolithic belts under the floor slabs are applied as crossbars.

The calculation outcomes indicate that the stress-strain state of the load-bearing walls does not change significantly compared to the option without hidden rod elements (Figures 8 and 9), and the presence of hidden elements will cause the increase of the reinforcement cost.

The findings of the analysis of the carried-out numerous researches of the stress-strain condition of bearing and self-bearing walls from permanent formwork ComBlock units for buildings of various constructive schemes allow to come to the following conclusions.
It has been proved worthwhile to perform the calculation of low-rise buildings using permanent formwork ComBlock under construction in areas with normal soil conditions in non-seismic areas without hidden columns and crossbars in the following sequence:

1. The constructive system and the corresponding calculation scheme of the building are accepted on the basis of the offered architectural and design solutions.

2. The gradual calculation of the load-bearing walls (columns) of the building is performed using the appropriate software packages (for example, LIRA-SAPR or MONOMAKH-SAPR).

3. The received forces in walls (columns) are analysed and two possible algorithms of the further calculation are considered depending on the received results:
   - in case of the absence of stresses in the structural elements, which exceed the calculated tensile strength of concrete, i.e. \( \sigma < f_{cd} \), testing design calculation of sections both for structures of non-reinforced and low-reinforced concrete is performed in accordance with the requirements of section 12 of DBN V.2.6-98:2009, section 9 of DSTU B V.2.6-156:2010. Structural reinforcement of load-bearing elements of the building is developed, including areas above the slots in the walls (jumpers) and joints of walls with floors and coverings corresponding to the requirements of state building codes and design solutions proposed by the authors.
   - if stresses take place in the structural elements that exceed the design characteristics of concrete tensile strength, i.e. \( \sigma \geq f_{cd} \), the calculation of reinforcement of load-bearing walls and columns of the building is performed (continued) by means of software packages. Reinforcement of bearing elements of the building is developed on the basis of the specified calculation.

The outcome analysis of the performed numerical researches testifies that it is necessary to carry out the specified sequence when designing each object separately within designing bearing walls of low-rise buildings with the use of permanent formwork.

4. Conclusions
The obtained research findings revealed that it is possible to minimize the consumption of reinforcing steel in monolithic concrete walls made with permanent formwork ComBlock units.

Design (working) reinforcement in load-bearing vertical elements of such buildings should be installed only in cases where stresses occur in structural elements that exceed the calculated tensile strength of concrete.

For the most frequently used architectural-design and structural solutions of low-rise buildings,
which are erected in areas with normal soil conditions in non-seismic areas, their vertical reinforcement is not required due to the absence or presence of insignificant tensile forces in the walls. In this case, they can be made of non-reinforced or low-reinforced concrete with structural reinforcement, including joints between walls themselves, walls with floors and coverings and areas above the slots in the walls (jumpers).

Herewith, it is important and necessary to perform the proposed above sequence of calculations and design for load-bearing walls of such low-rise buildings. That allows to minimize the cost of reinforcement for each object individually, taking into account it’s architectural and design features and construction conditions as well.

The proposed calculation method can be used in the design of low-rise buildings with load-bearing monolithic concrete and reinforced concrete walls with other technologies of their construction.

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