Wall panels for agricultural and industrial buildings

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Abstract. The authors develop a new construction, manufacturing technology and method of calculating three-layer wall panels with heat-insulating packages embedded in a contour frame of lightweight concrete for agricultural and industrial buildings. The proposed technical solution gives the wall panels a number of significant distinguishing properties: the outer and inner plates of the heat-insulating package of the panel along the contour are embedded in the monolithic reinforced concrete frame; a layer of insulation is embedded in the contour frame, which ensures a decrease in its thermal conductivity; embedding of plates and insulation in the contour frame minimizes the labor capacity of the elements connection; placing a layer of insulation between two pre-made plates.

1. Introduction

The cost of the cladding structures of the agricultural or industrial building walls is about 10 – 12% of the estimated cost of the entire building [1]. In this regard, the choice of the most economical and industrial structures of the walls of agricultural and industrial buildings is an important and urgent task. One of the ways to solve this important task is to create new, more efficient wall structures using lightweight concrete and other innovative materials [2-4].

Single-layer wall panels with lightweight concrete are widely used in the construction of agricultural and industrial buildings. The mass of 1 m² of a wall from such panels is 270 ÷ 400 kg. The main disadvantage of such structures is their large own weight, due to the considerable thickness of the panel, assigned from the condition of thermal conductivity, and the reinforcement requirements of the panel is largely determined by their weight. Up to 30% of the country's energy carriers are used for heat supply of buildings made of single-layer wall panels, which indicates the urgency of increasing thermal resistance and the use of innovative insulation materials in wall cladding structures of an agricultural or industrial building [5].

Increase of the thermal resistance of the cladding structures and their technical and economic parameters will allow the transition from single-layer panels to multi-layer effective structures, in particular to wall three-layer panels with heat-insulating packages embedded in a reinforced contour frame made of lightweight concrete, due to the full functional use of the properties of carrier and heat insulating materials. The use of such three-layer wall panels with heat-insulating packages embedded in a reinforced contour frame made of lightweight concrete has not lost its relevance today as compared with the widely used light-weight three-layer panels in the construction of pre-fabricated structures [1].
2. The proposed panel structure

The proposed wall panel is a three-layer heat-insulating package consisting of outer and inner plates and a layer of thermal insulation between them, which is embedded in a reinforced contour frame made of lightweight concrete. The outer and inner plates of the heat-insulating package are made precast and embedded in a reinforced concrete contour frame of lightweight concrete in such a way that the layers of plates are released beyond the layer of insulation. At the same time, the depth of the insulation of the heater in the contour frame creates equal thermal conductivity from different external edges of the ribs to the internal surface of the structure. The junction of the plates and the thermal insulation with the edge of the frame is designed so that the thermal conductivity of the frame between the side edges of the rib and its vertical surfaces are approximately the same [2 - 4].

The proposed solution allows the use of lightweight, cheap mineral wool-type insulation and other local insulation materials for wall panels; the use of expensive heaters is not excluded. In accordance with the proposed technical solutions, the heater may not have a constructive connection with the plates of the panel, it may be glued to the plates, it may be foamed between them, it is possible to connect the plates with each other and with the heater with the help of connections. The connection between the plates allows increasing their bearing capacity, which is effective for thin plates that do not have sufficient strength [6 - 9].

The proposed technical solution gives the wall panels a number of new significant distinguishing properties:

- the outer and inner plates of the thermal insulation package of the panel are embedded in a monolithic reinforced concrete frame along the contour. The sealing of the plates along the contour ensures that they work as clamped plates or shells, which increases the load-bearing capacity of the plates compared to panels in which the plates are not clamped;
- a layer of insulation is embedded in the contour frame, which ensures a decrease in its thermal conductivity;
- plates and insulation embedding in the contour frame minimizes the complexity of the elements connection;
- placement of a layer of insulation between two pre-made plates, the collision of plates in a contour frame opens up wide possibilities for use of insulation and plates of various materials in three-layer wall panels. This significantly reduces the weight of the structure, the consumption of materials for it, and the insulating properties can be easily improved.

The nominal dimensions of the developed panel design correspond to the dimensions of typical panels for the series 1.432-14 / 80 (1180×5980, 1480×5980, 1780×5980 mm, etc.). The height of the contour edge corresponds to the thickness of the panel for the corresponding area and type of building. The thickness of the three-layer part of the panel is determined by thermal calculation, based on the thermal insulation properties of the insulation used [10-12].

Contour ribs are made of expanded clay concrete with a bulk weight of up to 1200 kg / m³ and concrete class B5 or B7.5. Longitudinal contour ribs are reinforced with a flat mesh with working reinforcement with a diameter of 6 ÷ 10 mm of class A-II or A-III, and transverse ones - with a flat mesh with working longitudinal reinforcement with a diameter of 6 ÷ 8 mm A-1, it is also possible to use composite reinforcement [6].

The proposed options for three-layer wall panels, as compared with standard panels, allow:

- reducing the weight of structures in 1.6 – 2.8 times;
- reducing the consumption of concrete in 1.7 – 2.7 times;
- reducing the consumption of valves by 17 – 46%;
- reducing the cost of panels in 1.4 – 1.6 times;
• increasing the thermal resistance of the structure and reducing the cost of heating buildings in 1.5 – 2 times.

Reducing the weight of structures, concrete consumption and energy consumption of the panel is due to a significant reduction in the consumption of expanded clay concrete the panel requires. Cost savings in reinforcement is due to reduced weight of the structure. In addition, in solid expanded clay panels, the amount of reinforcement for structural reasons depends on the concrete cross sections. In the proposed solution, the area of the concrete section is reduced several times, and therefore the limit on the minimum section reinforcement ceases to be decisive.

The question of the complexity of the manufacture of panels depends on the development of the industrial method of mass production of plates for them and the industrial method of their installation and the insulation of three-layer packages. It should be noted that the reserves to reduce the complexity of the proposed structures are to reduce the amount of work on the manufacture, transport and laying of expanded clay concrete into the panel, to reduce the complexity of transportation and installation of lighter structures.

It should be noted that the abovementioned technical and economic indicators of the panels are not ultimate, but have reserves of savings. These reserves are manifested when comparing structures of greater height, for example, for the PS 600.18.25 panel, the volume of concrete decreases by 2.34 cubic meters, i.e. 4.2 times, etc. other indicators. The proposed design solution is particularly effective for the regions of the Far North, since the thickness of the walls is determined by the conditions of their thermal conductivity and reaches 50 cm of lightweight concrete [6].

3. Theoretical part
The Existing strength analysis methods suggest the same calculations as for a multi-layer beam. For the calculation of wall panels with heat-insulating packages – the same as for a multi-layer beam, taking into account the actual rigidity of fixing flat outer layers in the concrete of the contour frame, the differential dependences of K Stamm and H Witte [13]:

\[
\left(1 + \frac{N}{A}\right) \cdot W_M^{\prime\prime} - \frac{N}{B_s} \cdot W_M^{\prime\prime} = \frac{g}{B_s}
\]

\[
\left(1 + \frac{N}{A}\right) \cdot W_M^{\prime\prime} - \frac{N}{B_s} \cdot W_M^{\prime\prime} = -\frac{g}{B_s}
\]

where \(N\) is the longitudinal force, \(A\) is the stiffness of the middle layer (insulation), \(B_s\) is the stiffness of the outer layers, \(g\) is uniformly distributed load, \(W_M\) is deflection due to lateral force, \(W_M\) is deflection from the action of bending moment.

The general solution of the equations is sought by the method of separate deflections from the bending moment and from the transverse force.

A technique was developed that allowed the calculation of three-layer elements as multicomponent structures, with different strength and deformative properties of concrete, reinforcement and material of the thermal insulation package for the formation of cracks in skew bending in the presence of normal forces (concrete shrinkage, temperature difference in heat-insulating package, moisture swelling by external layers of heat-insulating package and pre-stressing of reinforcement). Equivalent compressive and tensile forces in concrete are obtained by integrating the distribution functions of normal compressive and tensile stresses over the areas of the compressed and stretched zones.

The coordinates of the gravity center of the stress profile in the compressed and stretched zones of concrete are obtained by dividing the static moments of the stress diagram relative to the vertical and horizontal axes by the values of the resultant compressive and tensile forces. The height of the compressed zone of concrete is determined from the condition of equilibrium of all forces on the longitudinal axis of the element. The calculation was carried out by the iteration method. When
calculating the formation of cracks for a complex section of a three-layer panel with different strength and deformative properties, 9 cases of the possible position of the neutral line are considered at tilt angles of the plane of the moments of external and internal forces effects from 0° to 90° [13-16]. This condition is fulfilled in a cycle by rotating the neutral section line. The analysis of the calculation of wall panels for cracking according to the proposed method was confirmed by experimental studies conducted, which satisfactorily confirmed the verity of the decisions made [13-18].

4. Experimental part
The designs of wall panels with heat-insulating bags have been experimentally tested [19]. The testing of wall panels was carried out on the device under the simultaneous actions of horizontal and vertical load [20,21]. The loads were adjusted to a standard value with their subsequent proportional increase in stages until the panels were destroyed. When testing the movement of the panels, the width of the opening cracks, deformation of reinforcement and concrete were determined. The degree of deformations in the concrete was close to prism strength. Wall panels collapsed in the middle section of the tension reinforcement. The intensity of breaking horizontal distributed loads in the experimental panels varied from 2.3 kN/m to 6.1 kN/m. At the same time, the vertical loads, taking into account their own weight, varied from 3.1 kN/m to 7.8 kN/m. The panels collapsed when the calculated combination of loads exceeded 1.7 - 2.4 times, thereby confirming the accepted theory of strength. According to the results of the experiments, the deflections at standard loads in the panels ranged from 2.2 to 10.62 mm, which is respectively 2.73 - 13.6 times less than the maximum permissible value equal to 29 mm. The first cracks in the panels occurred at loads exceeding the standard value, respectively, of 1.09 – 1.36 times, while the crack opening width was 0.03 – 0.1 mm. For the experimental panels, the maximum horizontal displacements for the normative loads amounted to 1/590 to 1/2700 of the calculated span, the maximum width of crack opening in the panels was 0.03-0.1 mm. The results of calculations of experimental panels for cracking during skew bending, as multilayer structures showed better convergence with experimental data than in the calculation of plane-bendable multicomponent elements. Theoretical and experimental moments of crack formation during skew bending differed by only 4-14%.

5. Conclusions
1. A new construction, manufacturing technology and method for calculating three-layer wall panels with heat-insulating packages embedded in a light-weight contour frame for agricultural and industrial buildings have been developed.
2. The proposed technical solution gives the wall panels a number of significant distinguishing properties:
   - the outer and inner plates of the heat-insulating package of the panel along the contour are embedded in a monolithic reinforced concrete frame;
   - a layer of insulation is embedded in the contour frame, which ensures a decrease in its thermal conductivity;
   - plates and insulation embedding in the contour frame minimizes the complexity of the elements connection;
   - placing a layer of insulation between two pre-made plates.
3. Constructions of wall panels with heat-insulating packages were tested experimentally. They have the strength, stiffness and crack resistance required by GOST 8829-94.
4. The developed method of experimental studies of wall panels with insulating packages embedded in a contour frame, the simultaneous action of horizontal and vertical loads provided reliable experimental data. Wall panels were destroyed when the calculated combination of loads was exceeded by 1.7 – 2.4 times, thereby confirming the accepted theory of strength.
5. A method has been developed for calculating a wall panel with heat-insulating packages embedded in a light-weight contour frame for the effect of a uniformly distributed load over its
surface. The calculation of the panel is composed of a beam calculation and an additional one that takes into account the deformation of the thermal insulation package together with the contour frame.

6. A method for calculating a wall panel with heat-insulating packages embedded in a contour frame of lightweight concrete with a skew bending has been developed. The results of calculations of experimental panels for crack formation during skew bending, as multilayer structures give better convergence with experimental data than in the calculation of plane-bendable multicomponent elements. The discrepancies between the theoretical and experimental moments of destruction amounted to 4-14%.

7. The developed method of calculation is applied during the design of production drawings, technical conditions and construction of agricultural and industrial buildings. The economic effect of using a wall panel with heat-insulating packages is 150–160 rubles by reducing the cost of 1 m² of a wall, and 100–120 rubles by saving energy resources for heating per 1 m² of wall per year (in 2015 prices).

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