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STRUCTURAL AND THERMAL BEHAVIOR OF MULTILAYER WALL SYSTEMS WITH ADVANCED INSULATION COATINGS: DEFORMATION ANALYSIS AND PERFORMANCE EVALUATION

Abstract. The article is devoted to the analysis of the deformation characteristics of multilayer wall structures with effective thermal insulation coatings and the development of calculation methods that take deformations into account based on the provisions of SNiP 2.03.01-84*. The relevance of the study is driven by increased requirements for the thermal protection of building envelopes and the need to ensure energy efficiency in buildings. Aim of the work is to develop a method for calculating the deformations of such structures, taking into account their specific structural behavior, including the interaction between layers and the formation of cracks in the support zones. The scientific novelty lies in the acquisition of experimental data on the deformation characteristics of three-layer structures, the refinement of the physical and mechanical properties of arbolite, as well as proposals for taking into account the influence of transverse reinforcement and shear deformations in the calculation of bending elements.

Keywords: thermal resistance of enclosing structures; heat transfer resistance coefficient of walls; heat flux; sandwich wall panel; flexible ties; strength of reinforced concrete structures; crack resistance of reinforced concrete structures.

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Introduction. Modern construction is inconceivable without reinforced concrete structures, the most common of which are enclosing structures. As society evolves, so do the requirements for these structures. Due to the non-renewable nature of energy resources, there is a constant increase in the demands placed on enclosing structures, particularly regarding their thermal resistance, in order to reduce energy consumption during the operation of buildings and facilities. Today, traditional single-layer structures, whether made of lightweight concrete, brick, wood, or cellular concrete, no longer meet current thermal and economic standards and are gradually being replaced by a new generation of structures with high thermal insulation properties: three-layer panels.

Energy consumption in Kazakhstan's public utilities represents 38% of the total expenditure on fuel and energy resources. Heat losses through the external parts of buildings are influenced by the thermal insulation properties of the structures. The highest losses occur through the walls, which significantly impact the indoor climate. Walls can account for up to 45% of heat loss, with heat transfer depending on the material's thermal conductivity. Moisture increases the material's heat transfer rate, lowering its insulation efficiency. For example, as the moisture content in brick rises, its thermal insulation capacity decreases by 30%.

Windows contribute to 20-30% of heat loss due to their much lower heat resistance compared to walls. Wind exacerbates heat loss through windows, as it can penetrate through porous materials. Heat loss through first-floor slabs ranges from 3% to 10%. Significant heat loss also occurs through the roof in winter, especially in single-story homes, with losses reaching up to 35%. Ventilation also plays a role in heat loss, as excessive air volume often surpasses recommended levels, increasing heating costs by up to 15%.

Therefore, the typical breakdown of a building's heat energy consumption is as follows (Fig. 1).

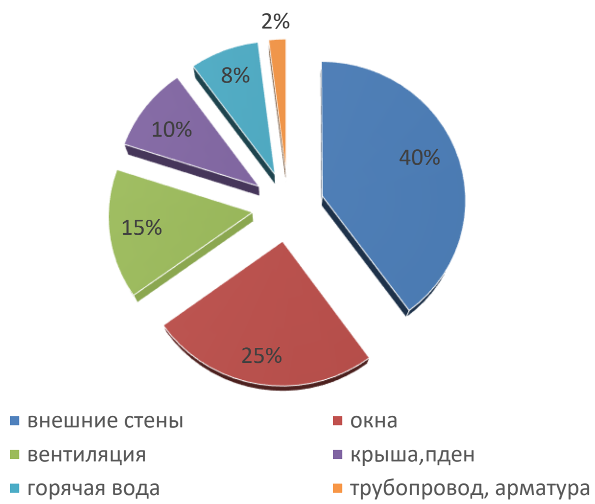


Fig. 1. Structure of a building’s heat energy consumption

At an average outdoor temperature of -25°C and a heating season lasting 5 months, the annual heat energy consumption for heating residential spaces in one- to two-story buildings is 766.8 kWh/m². The relatively high energy consumption in buildings within our country, compared to other countries, is largely due to the fact that most existing buildings were constructed according to the building codes and standards that were in effect at the time of their construction.

Increasing the thermal resistance of structures is a key focus in CIS countries. In Russia, regulations have been in place since 1994 to improve the thermal performance of building envelopes. For example, to save energy, the use of single-layer panels with a density greater than 900 kg/m³ was banned, and they were replaced with sandwich panels featuring thermal inserts. In 1995, Amendment No.

3 to SNiP II-3-79 was implemented, raising the thermal resistance of walls from 1.16 m²·°C/W to 2.2 m²·°C/W, which resulted in a 17% reduction in heating costs [1,2].

Since 2000, Russia has moved to the second phase of energy efficiency, aiming to achieve an R-value of 3 m²·°C/W, which would reduce heat loss by 22%. This is accomplished by using sandwich panels with polystyrene insulation and point connections to prevent “thermal bridges.”

Kazakhstan is also working towards improving thermal performance, with standards such as SN RK 2.04-21-2004 and regulations for residential and public buildings (thermal resistance requirements range from 2.1 to 3.8 m²·°C/W). Legislative efforts, like the “On Energy Saving” Law (2012) and Government Decree No. 1115, aim to enhance energy efficiency. Research indicates that traditional exterior wall structures no longer meet modern thermal insulation standards.

To improve thermal protection, walls should be equipped with effective insulation. Medium-density concrete (300-500 kg/m³), with a thermal conductivity coefficient 2.5 to 4 times lower than that of single-layer materials, is ideal for the middle insulating layer of sandwich panels [3]. Various traditional and innovative filling aggregates are used, such as perlite, expanded clay, foam glass granulate, as well as wood processing waste and polymer granules, which reduce thermal conductivity by 25-30%.

Thermal insulation of concrete can be enhanced by 20-30% through the use of low-energy binders made from industrial waste or volcanic rocks. The use of sandwich construction improves heat transfer resistance by 2 to 2.5 times, reduces material consumption, and helps maintain a regulated indoor climate.The use of sandwich construction is technically feasible, as they reduce the weight of enclosures by 4-5 times, increase spacings, improve seismic resistance, and allow for free layout. This also enhances construction quality, thermal insulation, sound insulation, and the aesthetic characteristics of buildings.

Sandwich construction enhances heat transfer resistance by 2 to 2.5 times, reduces material consumption, and improves indoor thermal and humidity conditions. It also reduces the weight of building enclosures, allows for larger spacing between structural elements, boosts seismic resistance, and offers greater flexibility in layout design. As a result, construction quality improves, along with thermal and sound insulation properties, and the overall aesthetic of buildings is enhanced.

The formation of separate layers increases the precision of panel thickness and thermal insulation properties. This method permits the use of different insulating materials, including filling materials, while preventing thermal bridges. It also makes it possible to effectively use compressible and moisture-absorbing insulation without compromising thermal efficiency.

The Central Scientific Research Institute of Construction has developed sandwich panels that meet the SNiP II-3-79* “Thermal Engineering for Construction” standards, providing a heat transfer resistance between 2.6 and 3.1 m²·°C/W. These panels can be produced with standard equipment and are suitable for various climatic conditions. They feature load-bearing concrete layers connected by reinforced concrete water stops that prevent freezing.

Compared to panels with flexible ties, these new panels offer several benefits, such as the ability to substitute expanded clay with standard concrete, higher strength, dependable thermal insulation, and a 30% reduction in labor costs. Moreover, they save up to 25% of concrete and enhance the rigidity of the panels.

Modern sandwich panels with insulation made from lightweight concrete, such as arbolite, contribute to reducing both labor costs and material consumption in construction. For warm attic coverings, panels incorporating various layers, including arbolite and expanded clay concrete, are being developed [4].

Using polystyrene concrete as insulation enhances the thermal efficiency of structures, resulting in material savings and cost reductions. In several countries, polystyrene concrete is successfully utilized in the production of sandwich panels, improving the thermal and operational properties of buildings.

Sandwich construction with lightweight concrete is also commonly used in international construction, particularly in countries like Sweden, Finland, and Belgium. Ongoing advancements in concrete mix development and manufacturing technologies continue to expand the applications of such panels in various environments.

In residential buildings, sandwich panels experience eccentric compression due to their own weight and floor loads, while those in industrial, public, and agricultural buildings are subject to oblique bending. According to Industry-Specific Construction Standards-32-77, the strength calculation for panels with “non-rigid” connections between layers is carried out without considering their joint functionality. Connections are deemed “rigid” if the strength of the insulation layer is at least 35 kg/cm² and proper bonding between the layers is ensured.

Research by V.S. Uvarov [5] has indicated that the combined action of layers increases the load-bearing capacity of the inner layer by 1.3 to 4 times. Insulated panels can have greater strength than non-insulated ones if the impact of the outer layer is taken into account.

On the other hand, studies by V.G. Tsimbler and other researchers have shown that while insulated panels have a higher load-bearing capacity, their strength is mainly determined by the load-bearing layer, rather than the crack resistance of the outer layer.

N.V. Morozov introduced a method for calculating insulated panels as structural components in systems with metal lattice bracings. He highlighted the necessity for further investigation into the strength of sandwich panels with localized bracings.

The calculation of such panels for industrial and agricultural buildings is typically done approximately, considering the horizontal load applied to either the inner layer or both layers, depending on the method used. The Central Research Institute of Engineering Design (CNIIEP) has confirmed the validity of this approach [6], but additional research is required.

Design guidelines for sandwich panels with flexible connections suggest accounting for the combined action of layers, determining the cracking moment and deflections using formulas that still need further experimental validation.

Theoretical and experimental studies on the development and improvement of the analysis of multilayer structures were carried out by A.Ya. Aleksandrov, L.E. Bryukker, L.M. Kurshin, A.P. Prusakov [6,7,8], A.T. Arkhangorodsky, B.Ya. Rozendent [9], E.I. Grigolyuk [10], A.Ya. Aleksandrov, M.Ya. Borodin, V.V. Pavlov [11], Sh.A. Nazirov [12], K.Sh. Bobomuradov, V.K. Kabulov [13], T.Sh. Shirinkulov, A.G. Temirov [14], O. Jungbluth [15], and others, who laid the theoretical foundations for the analysis of three-layer structures. The analysis of monolithic reinforced concrete structures was studied by B.V. Gorenstein [16], A.A. Evdokimov and L.N. Brusakova [17], I.L. Zhodzishsky and V.G. Zolotukhin [8], N.A. Kornev and A.A. Akbarov [19], A.A. Kudryavtsev [20].

Experimental data have been collected for two types of cross-sections: two-layer sections made of heavy and lightweight concrete, with low-strength concrete placed in either the compressed or tensioned zones, and three-layer sections, where the outer layers consist of heavy or dense lightweight concrete, and the middle layer is predominantly made of low-strength materials such as foam concrete, large-pore concrete, arbolite, polystyrene concrete, and others.

Many researchers propose calculating sandwich reinforced concrete elements with monolithically connected layers based on the ultimate limit states of the first and second groups. This approach uses current standards while taking into account the variations in the strength and deformation properties of the concrete layers.

Although current standards do not provide specific recommendations for calculating monolithic multi-layer elements, most authors agree that it is appropriate to apply existing methods while considering the geometric characteristics and differences between layers.

Materials and methods. The study of the deformative characteristics of three-layer wall structures with monolithically bonded layers was carried out under laboratory conditions using experimental and theoretical methods in accordance with the requirements of regulatory documents SNiP 2.03.01-84, GOST 10180-78, and GOST 24452-80.*

To conduct the experiment on studying the light resistance, deformation characteristics, and strength of three-layer flexible elements with a thin insulation layer, a test beam was fabricated with a length of 330 cm, a span of 300 cm, and a cross-section of 25×16 cm (Table 1).

The beam dimensions were selected to closely approximate the cross-sectional geometry of actual enclosing building structures under real operating conditions. The thickness of the outer layers was set at the minimum value of 4 cm to ensure reliable protection of the reinforcement from corrosive environmental effects. Arbolite concrete with an organic filler made from crushed cotton stalks was used as the raw material for the middle layer, allowing the use of locally available resources and reducing the overall material cost.

Table 1

Outlines of test samples

Outline	Name	Characteristic	Varied factors
3	4	5	6
	BA-I-1 BA-I-2 BA-I-3 BA-I-4 BA-I-5 BA-I-6 BA-I-7 BA-I-8	The samples are three-layered with insulation made of arbolit concrete, reinforced with two longitudinal Ø12 bars made of A-III class steel	Vertical transverse reinforcement (Ø4,5; 5,66;6,93;8;8,94;9 mm)

Methods of Data Processing

For the analysis, the following approaches were used:

1. Comparison of experimental deflections with theoretical values, calculated:

– Using the classical formulas of SNiP;

– Using refined relationships that take into account the cross-sectional shape and the behavior of layers;

– Using adjusted coefficients φcrc and Ψb for lightweight concretes.

2. Determination of the influence of transverse reinforcement on:

– Deflections caused by shear forces;

– Shear stiffness;

– Development of inclined cracks.

3. Assessment of the cooperative behavior of layers under crack formation conditions.

4. Selection of optimal coefficients for calculating deformations of three-layer elements.

Research Materials

The study focused on experimental three-layer rectangular beams, which comprised:

– Outer layers of heavy concrete with a compressive strength of 25 MPa and a thickness of 4 cm;

– A middle layer of arbolite concrete with a density of approximately 500 kg/m³ and a compressive strength of 1 MPa, produced using cotton stems up to 40 mm in length;

– Longitudinal reinforcement consisting of two Ø12 mm steel bars of class A-III;

– Transverse reinforcement consisting of vertical steel bars Ø4-9.8 mm of class A-I, spaced at 21 cm (this parameter was varied);

– Two beams were fabricated without transverse reinforcement.

For the concrete of the outer layers, crushed stone (5-10 mm fraction), quartz sand with a density of 1540 kg/m³, and M400 cement were used. The middle layer incorporated an air-entraining additive (SDO) at 0.25% of the cement mass.

Specimens Fabricated

A total of the following specimens were produced:

– Eight three-layer beams, each 330 cm in length (effective span 300 cm) with a cross-section of 25×16 cm;

– Cubes measuring 15×15×15 cm and 10×10×10 cm – 6 pieces;

– Prisms measuring 15×15×60 cm and 10×10×40 cm – 54 pieces;

– Control specimens of both types of concrete were prepared from the same mixes as used for the beams.

Specimen Preparation Conditions

The concrete was mixed in a forced-action mixer, and the layers were placed sequentially in metal, demountable molds with vibration compaction. After casting, the specimens were cured in the molds under moist sawdust for 14 days, then demolded and stored under standard conditions until testing.

Reinforcement cages were fabricated using spot welding (MTP-75 machine), with flat cages combined to form spatial frameworks.

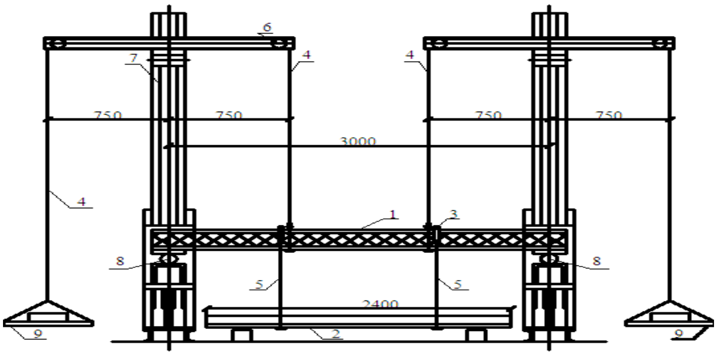
Testing Equipment

A stationary test rig was used for beam testing (Fig. 1), consisting of:

– Four vertical posts;

– Two hinged roller supports;

– A traverse block for applying concentrated loads;
– A system of cables and weights for suspending the beam;
– A loading platform with sets of individual 20 kg weights.
– The measurement system included:
– Deflectometers with an accuracy of 0.001-0.01 mm;
– Dial indicators for recording deformations;
– Strain gauges for monitoring deformations in both reinforcement and concrete.



1 –beam testing; 2 – load platform; 3 – П-shaped traverse; 4 – wires; 5 – tension bars; 6 – blocks; 7 – frames; 8 – ball-bearings; 9 – a with a load for alignment of beams and a cargo platform

Fig. 1. A test stand for three-layer beams with monolithically bonded layers

Testing Methodology

The beams were loaded in increments corresponding to 1/20-1/25 of the estimated ultimate load. At each load step, the load was maintained for 10-15 minutes to record measurements. Upon the appearance of initial cracks, the load increment was halved.

At each stage, the following were recorded:
– Midspan deflections;
– Deformations of the outer and inner concrete layers;
– Deformations of longitudinal and transverse reinforcement;
– Growth and characteristics of normal and diagonal cracks.
– Deflections were also separately determined for:
– Bending moments;
– Shear forces;
– Total deflections, calculated as the sum of the two components.

For comparison with experimental results, theoretical calculations were carried out using structural mechanics formulas and in accordance with SNiP 2.03.01-84*, taking into account:
– The transformed I-section;
– Initial elastic moduli of the concretes;
– Creep coefficients φb_1;
– Coefficients Ψb and Ψs for cracked stages;
– Cross-section shape factor K;
– Coefficient φcrc for shear-induced cracks.

Testing of Arbolite Concrete

For arbolite concrete with a density of 500 kg/m³, the following properties were determined:

– Compressive strength of cubes and prisms;
– Axial tensile strength;
– Initial modulus of elasticity;
– Compressive and tensile deformations up to failure;
– Shrinkage deformations measured on 10×10×40 cm prisms.

Testing was carried out in accordance with GOST 10180-78 and GOST 24452-80. Shrinkage was monitored throughout the entire curing period, with the most active phase occurring during the first 70-80 days.

The strength properties of arbolite concrete are summarized in Table 2. The average cubic and prismatic strength values were calculated as the arithmetic mean of each sample in the series.

Table 2

Cubic and prismatic strength, MPa

Cubic strength, R_m		Prismatic stregnth					
		Compressive stregnth R_b			Tensile strength R_{bt}		
One	Middle	One	Middle	R_b/R_m	One	Middle	R_{bt}/R_m
1,01	1,04	0,76	0,78	0,75	0,28	0,26	0,25

The dependence of prism strength on cubic strength for concretes is expressed as:

$$R_b=R_m(0.77-0.001R_m) \qquad (1)$$

but should not be less than 0,72.

For low-strength concretes, the coefficient is 0.77, decreasing to 0.72. In SNiP 2.03.01-84, the coefficient varies from 0.744 to 0.80. For arbolit concrete, the ratio of axial tensile strength to cubic strength is 0.25.

If the tensile strength is proportional to the cubic root of the cubic strength, then K_1=0.199, which is close to the values in SNiP 2.03.01-84.

Deformation characteristics of arbolit concrete are given in Table 3.

Table 3

Deformation characteristics of arbolit concrete

Cubic strength R_m	Tangent modulus of elasticity E_b	Compressive deformation before destruction ε_b	Tensile deformation before destruction ε_{bt}	Shrinkage ε_{shr}	Coefficient ν
1.04	530.0	3.12…3,25	2,3…2,5	5,1	0,2

Data Processing Methods

The analysis was conducted using the following approaches:

1. Comparison of experimental deflections with theoretical values, calculated:

– Using classical SNiP formulas;
– Using refined relations that account for cross-section shape and layer behavior;
– With corrected coefficients φcrc and Ψb for lightweight concretes.

2. Determination of the influence of transverse reinforcement on:
– Deflections due to shear forces;
– Shear stiffness;
– Development of diagonal cracks.
3. Evaluation of the cooperative behavior of layers under cracking conditions.
4. Selection of optimal coefficients for calculating deformations of three-layer elements.

Research results and discussion. The experiment showed that three-layer beams with monolithically bonded layers work together across the entire height of the cross-section until the appearance of cracks. In the initial loading stage, the deflections changed linearly, which corresponds to the behavior of the structure within the elastic range. After the formation of the first vertical cracks, a reduction in stiffness was observed, but the bond between the layers was maintained, confirming the reliability of the monolithic connection. In beams without transverse reinforcement (BA-3, BA-4, BA-5, BA-6, BA-7, BA-8), the ratio of deflection caused by shear force to deflection caused by bending was between 0.56 and 0.59. In beams with transverse reinforcement, this ratio ranged from 0.52 to 1.05 (Table 4). Following crack formation, shear stiffness decreased, and the fq / fm coefficient increased.

Table 4

Experimental deflection values before crack formation and under service loads (0.3…0.7) Q_{max}

Beam reference	Before crack formation					
	Q кН	M кН·м	$f_{tot}\cdot 10^3$ см	$f_m\cdot 10^3$ см	$f_q\cdot 10^3$ см	f_q / f_m
BA-1	2,8	1,76	50	32	18	0,56
BA-2	2,4	1,51	43	27	16	0,59
BA-3	2,0	1,26	32	21	11	0,52
BA-4	2,4	1,51	47	25	22	0,88
BA-5	2,4	1,51	45	27	18	0,67
BA-6	2,0	1,76	42	20	22	1,1
BA-7	2,0	1,26	43	22	21	0,95
BA-8	2,0	1,26	45	22	23	1,05
Beam reference	During operation load					
	Q кН	M кН·м	$f_{tot}\cdot 10^3$ см	$f_m\cdot 10^3$ см	$f_q\cdot 10^3$ см	f_q / f_m
BA-1	4,0	2,52	87	48	39	0,81
BA-2	4,0	2,52	113	65	4	0,74
BA-3	4,0	2,52	110	48	62	1,29
BA-4	4,4	2,77	126	54	72	1,33
BA-5	4,4	2,77	142	57	85	1,49
BA-6	5,2	3,28	209	73	136	1,86
BA-7	2,8	1,76	64	31	33	1,06
BA-8	3,2	2,02	110	37	73	1,97

The ratio f_q / f_m depends on bending and shear stiffness. After crack formation, it remains nearly unchanged, but before destruction, deflections due to shear increase significantly, leading to an increase in f_q / f_m.

In SNiP 2.03.01-84*, it is recommended to determine deflections for bending structures as the sum of deflections from bending and shear. When the span exceeds 10 times the section height, shear deflection can be neglected. For the studied sandwich beams, the ratio is 12. However, due to the low-strength concrete in the middle layer, the influence of shear was significant, and beam deflections were calculated considering both bending and shear deformations, which were then compared with experimental results.

The deflections from the bending moment for the sandwich samples were calculated as for homogeneous I-shaped cross-section, based on the initial elastic moduli of the concrete layers. Theoretical deflections were obtained using structural theory formulas (as per SNiP 2.03.01-84*).

$$f_m = \frac{M}{\varphi_{b1} E_b\ I_{red}} \rho_m l^2 \quad (2)$$

Table 5

Experimental and theoretical deflection values from bending moments at the midspan relative to the loads

Beam reference	Bending moment M, кН·м	Deflection $f_m \cdot 10^3$ см/%	
		Experiment	Calculation
BA-1	1.26	6.1/100	6.4/105
BA-2	1.26	6.3/100	6.4/102
BA-3	1.26	6.7/100	6.4/196
BA-4	1.26	6.2/100	6.4/106
BA-5	1.26	6.0/100	6.4/106
BA-6	1.26	6.6/100	6.4/97
BA-7	1.26	6.5/100	6.4/98
BA-8	1.26	6.8/100	6.4/94

The calculation results with φ_{b1}=1,0 were compared with the experimental deflections, showing a difference of -6 to +6%, which may be due to variations in elastic modulus and measurement errors.

The calculation of deflections for sandwich structures under bending moments before cracking can be performed using equation (2), replacing the three-layer section with a homogeneous I-shaped cross-section based on the initial elastic moduli of the concrete layers.

The use of arbolite concrete with a density of approximately 500 kg/m³ resulted in a reduction of the modulus of elasticity of the middle layer by about 6-7 times compared to normal-weight concrete. Despite this, the three-layer beams retained sufficient flexural stiffness due to the rigid outer layers. The tests showed that:

– the prismatic strength of the arbolite concrete was about 1 MPa;

– the modulus of elasticity was approximately 3000-3500 MPa, which is consistent with known literature data for lightweight concretes of similar composition;

– the ultimate compressive strain exceeded that of normal-weight concrete, providing more ductile behavior of the middle layer.

The obtained values are in good agreement with previously published experiments on lightweight concretes with plant-based aggregates, but they exhibit lower variability due to the denser structure of the material studied.

Comparison of beams with and without transverse reinforcement showed that:

– the presence of transverse bars significantly increased resistance to diagonal cracking;

– deflections caused by shear forces decreased by 12-20%;

– beams without transverse reinforcement transitioned earlier into the stage of intensive crack formation and had lower load-carrying capacity.

This confirms the importance of considering transverse reinforcement in three-layer elements, especially when lightweight aggregates are used, as they affect the structural behavior in the shear zone.

The first cracks appeared at loads corresponding to 40-55% of the ultimate load. The crack pattern confirmed the composite action of all three layers:

– vertical (flexural) cracks propagated from the outer layers toward the middle layer;

– diagonal cracks were less intensive when transverse reinforcement was present;

– crack opening did not lead to a loss of monolithic bonding between the layers.

Comparison with known data on three-layer structures showed similar patterns; however, in this study, a more uniform interaction of the layers was observed due to the technology of their combined vibration compaction.

Comparison of the results showed:

– Theoretical deflections calculated according to SNiP underestimated the actual deflections by 10-25%;

– Refined formulas, taking into account the coefficients Ψb, Ψs, and φcrc for lightweight concretes, yielded discrepancies of no more than 6-10%;

– Shear stiffness obtained from experiments was lower than the calculated values, which can be explained by the lower modulus of elasticity of arbolite concrete and its heterogeneous structure.

The results indicate the necessity of using modified coefficients for the design of three-layer structures, especially under conditions of combined action of heavy and lightweight concretes.

Conclusion. The physical and mechanical properties of arbolit concrete with a strength of 1 MPa have been studied, including data on compressive strength, axial tension, initial modulus of elasticity, compressibility, tensile capacity, deformability, shrinkage, and the Poisson’s ratio.

The deflections of flexural three-layer elements with low-strength arbolit concrete are caused not only by bending but also by shear deformations. Experimental data confirm the possibility of separately calculating deflections from the bending moment and transverse forces, followed by their summation.

The deflections from the bending moment of three-layer structures are recommended to be calculated using the methodology of SNiP 2.03.01-84*, replacing the three-layer section with a homogeneous I-beam section, taking into account the initial elastic moduli of the concrete layers. In the cracked stage, it is proposed to apply a coefficient $\Psi_b = 0.7$.

Reinforcement of the support zones with vertical bars increases the deflections from transverse forces. The influence of transverse reinforcement can be accounted for by reducing the initial elastic modulus of the middle layer concrete by 30%, after which calculations are performed similarly to beams without reinforcement.

Inclined and normal cracks affect the intensity of deflections from transverse forces. The recommendations of SNiP 2.03.01-84* for considering the influence of cracks lead to overestimated results. For beams without transverse reinforcement, the coefficient φ_{crc} for inclined cracks should be taken as 1.5, and for beams with reinforcement – 2, instead of 4.8, as specified in SNiP. The influence of cracks on deflections is also accounted for by the coefficient φ_{crc}, which is 1.5 for beams without transverse reinforcement and with vertical bars.

Theoretical analysis has shown that for three-layer structures with an initial modulus of elasticity of the middle layer greater than 20 MPa, material resistance formulas can be used to calculate deflections.

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ЖЕТІЛДІРІЛГЕН ЖЫЛУ ОҚШАУЛАУ ҚАПТАМАЛАРЫ БАР КӨПҚАБАТТЫ ҚАБЫРҒА ЖҮЙЕЛЕРІНІҢ ҚҰРЫЛЫМДЫҚ ЖӘНЕ ЖЫЛУ-ТЕХНИКАЛЫҚ ҚАСИЕТТЕРІ: ДЕФОРМАЦИЯЛАРДЫ ТАЛДАУ ЖӘНЕ ЖҰМЫС ІСТЕУІН БАҒАЛАУ

Аңдатпа. Мақала тиімді жылу оқшаулағыш қаптамалары бар көпқабатты қабырға конструкцияларының деформациялық сипаттамаларын талдауға және СНиП 2.03.01-84* талаптарына сәйкес деформацияларды ескеретін есептеу әдістерін әзірлеуге арналған. Зерттеудің өзектілігі ғимараттардың қоршау конструкцияларының жылулық қорғанышына қойылатын жоғары талаптармен және энергия тиімділігін қамтамасыз ету қажеттілігімен негізделеді. Жұмыстың мақсаты – қабаттар арасындағы әрекеттесу мен тірек аймақтарында жарықтардың пайда болуын ескере отырып, мұндай конструкциялардың деформацияларын есептеу әдістемесін жасау. Ғылыми жаңалығы – үш қабатты конструкциялардың деформациялық сипаттамалары бойынша эксперименттік деректер алу, арболиттің физика-механикалық қасиеттерін нақтылау, сондай-ақ көлденең арматураның және ығысу деформацияларының иілетін элементтерді есептеуде әсерін ескеру бойынша ұсыныстар әзірлеу.

Тірек сөздер: қоршау конструкцияларының жылулық кедергісі, қабырғалардың жылуөткізгіштікке кедергі коэффициенті, жылу ағыны, үш қабатты қабырға панелі, иілгіш байламдар, темірбетон конструкциясының беріктігі, темірбетон конструкцияларының жарыққа төзімділігі.

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СТРУКТУРНО-ТЕПЛОТЕХНИЧЕСКОЕ ПОВЕДЕНИЕ МНОГОСЛОЙНЫХ СТЕНОВЫХ СИСТЕМ С СОВРЕМЕННЫМИ ТЕПЛОИЗОЛЯЦИОННЫМИ ПОКРЫТИЯМИ: АНАЛИЗ ДЕФОРМАЦИЙ И ОЦЕНКА РАБОТОСПОСОБНОСТИ

Аннотация. Статья посвящена анализу деформационных характеристик многослойных стеновых конструкций с эффективными теплоизоляционными покрытиями и разработке методов расчёта, учитывающих деформации согласно положениям СНиП 2.03.01-84*. Актуальность исследования обусловлена повышенными требованиями к тепловой защите ограждающих конструкций и необходимостью обеспечения энергоэффективности зданий. Цель работы – разработка метода расчёта деформаций таких конструкций с учётом их специфического структурного поведения, включая взаимодействие между слоями и образование трещин в опорных зонах. Научная новизна заключается в получении экспериментальных данных о деформационных характеристиках трёхслойных конструкций, уточнении физико-механических свойств арболита, а также предложениях по учёту влияния поперечной арматуры и сдвиговых деформаций при расчёте изгибаемых элементов.

Ключевые слова: термическое сопротивление ограждающих конструкций, коэффициент сопротивления теплопередаче стен, тепловой поток, трехслойная стеновая панель, гибкие связи, прочность железобетонных конструкций, трещиностойкость железобетонных конструкций.