Technology for erecting monolithic enclosing structures of buildings made of expanded polystyrene concrete

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Abstract. This work aims to develop effective technology for erecting monolithic enclosing structures of buildings made of expanded polystyrene concrete. As a result of the research carried out, a model of large-panel formwork made of ABS plastic for concreting monolithic walls with an expanded polystyrene concrete mixture was developed, representing rectangular panels of a size of 3000 x 1200 x 40 mm. To ensure the necessary strength and rigidity, the outer side of the formwork is made cellular with a large number of longitudinal and transverse stiffeners placed in increments of 300 mm. We have developed a technology for erecting monolithic enclosing structures of buildings made of expanded polystyrene concrete using a mobile concrete-mixing unit. The following are technical and economic indicators for manufacturing monolithic walls out of expanded polystyrene concrete of a volume of 46 m³: the cost is 354.784 thousand rubles, and the labor intensity and unit capacity are 163.76 people.*h and 27.36 units.*h, respectively. The results significantly offer the construction industry a solution to reduce the labor intensity of construction and installation while manufacturing cost-effective monolithic enclosing structures for buildings.

1 Introduction

Based on the analysis of existing experiences on the use of expanded polystyrene concrete in construction, it may be concluded that this material was carried out mainly in producing prefabricated structures under factory conditions [1-2]. In this regard, one would be particularly interested in studying the potential use of expanded polystyrene concrete in the monolithic construction of buildings [3-4].

Currently, the technology of building monolithic construction is rapidly gaining momentum. One of the main advantages of this technology is associated with the high speed of monolithic construction. In addition, having a seamless wall, which is uncommon in building walls with blocks, can significantly improve the heat, sound, and noise insulation characteristics and increase the strength and durability of structures. It is worth noting that the cost of wall structures built of monolithic polystyrene concrete is lower than the cost of walls made of blocks [5]. With monolithic construction, there is no need to

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involve factories to produce wall blocks; there are no costs associated with transportation, loading and unloading, and lifting blocks to floors. One could produce an expanded polystyrene concrete mixture directly on the construction site. Thus, monolithic expanded polystyrene concrete makes it possible to achieve high economic efficiency in wall structure manufacturing [6].

Walls made of monolithic expanded polystyrene concrete can be erected in both stay-in-place and reusable formwork. Face work in one or half brick from the front side most serves as a stay-in-place formwork; less often do casing panels made of monolithic concrete [7]. When using brickwork, it should be checked by calculating the pressure of the polystyrene concrete mixture. Also, if necessary, it should be made sure that the brickwork is reinforced with temporary fasteners. Two-layer moisture-resistant plasterboard sheets, magnesia sheets, or cement-bonded particleboard can serve as formwork on the inside of a concreted structure. The connection between the outer brickwork and the inner sheets, serving as a stay-in-place formwork, is made using a reinforcing mesh and a perforated strip [8]. The strip is attached with one end to the mesh installed in the brickwork's horizontal seams and the other to the U-shaped galvanized profiles with the help of screws, onto which the internal facing sheets or panels are later on attached.

Another technical solution for monolithic enclosing structures made of expanded polystyrene concrete involves building a light metal frame, onto which a stay-in-place formwork's elements are attached on both sides [9]. The wall structure frame is inserted along the entire height of the floor using galvanized profiles, stainless steel, etc. Glass-magnesium sheets and cement-chipboard panels can also be used as elements of a stay-in-place formwork, while only two layers of moisture-resistant plasterboard sheets can be used inside. Using cement-chipboard panels on the outside and inside of the wall structure means you have to plaster these panels from the front side and face them with glass-magnesium sheets from the inside.

Sometimes, to make a building facade look vivid architecture-wise, elements of stay-in-place formwork can be used, imitating the pattern of natural stone or any other texture at the discretion of an architect. In this case, equivalent cement-chipboard panels or glass-magnesium sheets should be used, but with an additional decorative coating on top [10-11]. Also, there are technical solutions for using the textured panel, similar to those used in the suspended facade system.

Should a reusable formwork be used, small-panel plastic formwork, oriented chipboard, or plywood panels are most likely to be applied. To ensure the required fire and humidity conditions for the exterior walls, the structure surface must be plastered with cement-sand mortar of a layer thickness of at least 20 mm [12].

This work aims to develop a technology for erecting monolithic walls made of expanded polystyrene concrete and large-panel formwork made of ABS plastic.

2 Materials and Methods

Raw materials were used for manufacturing expanded polystyrene concrete: binder - Portland cement M400; modifying agent - metakaolin MK-40; foam-forming admix - "Penostrom"; superplasticizing admix; - Glenium 51; water that meets the requirements of GOST 23732-2011; crushed expanded polystyrene.

An expanded polystyrene concrete mixture was manufactured using a turbulent foam concrete mixer SPBU-150 Lux. The mixture components were fed through an open lid in the foam mixer vessel. The materials included in the mixture were mixed using a fast-rotating rotor in a stationary mixer vessel. When rotating, the rotor blades push the mixture out to the conical part of the mixer vessel. Three blades mounted on the vessel walls are
moving to slow down the mixture flow along the circumference and direct it spirally upward, leading to the mixture falling on the rotor and again ending up in the flow. The mixture was discharged from the overpressure mixer tank through the nozzle with the rotor switched off.

The polystyrene concrete mixture is made as follows. With the rotor off, water is supplied to the mixer tank with a pre-dosed amount of polystyrene pellets and additives - superplasticizing admix "Glenium 51" and the foam-forming agent "Penostrom". Then, when the rotor is on, the additives and pellets are mixed in water for 1 minute. After that, a pre-dosed amount of Portland cement and metakaolin is fed into the mixer, and the mixing continues. After 1 minute, compressed air is supplied to the mixing unit, meeting the required pressure value. The pressure in the mixer is monitored using a pressure gauge and maintained at the level of 0.09-0.1 MPa. Should the pressure drop, it should be promptly restored to the required value by supplying compressed air on-and-off. Further mixing should be done at constant pressure for 3-4 minutes. Due to excessive pressure in the mixer, the resulting expanded polystyrene concrete mixture is fed into the formwork when the rotor is off through the discharge pipe and maintained for 24 hours until gained in strength.

Using the technology described above, several prototype mixtures were produced to come up with the best possible expanded polystyrene concrete mixture, considering the obtained material's compliance with the requirements of the Russian standard 33929-2016. The overall view of the foam concrete mixer SPBU-150 Lux is shown in Fig. 1. The positions are as follows: 1 is electric motor; 2 is lubricating nipple; 3 is air supply pipe; 4 is pressure gauge; 5 is foam concrete mixer shaft; 6 is breather seal chamber housing; 7 is housing with sealing gland; 8 is air duct; 9 is air supply control valve; 10 is foam concrete mixture discharge pipe; 11 is overpressure relief valve.

Fig. 1. Overall view of the foam concrete mixer SPBU-150 Lux
3 Results and Discussion

Development of a large-panel plastic formwork model

Existing construction technologies for buildings made of monolithic expanded polystyrene concrete are based mainly on the use of a stay-in-place formwork [13]. In this paper, a model of large-panel plastic formwork for concreting monolithic expanded polystyrene concrete walls is being developed.

When developing a model of large-panel plastic formwork, a small-panel ABS plastic GEOPANEL formwork by GEOPLAST was used as a prototype [14]. The use of ABS (acrylonitrile butadiene styrene) as a formwork material is due to its high mechanical strength, ability to absorb shocks, stable operation at various temperatures (from -30° C to +70° C), high-end surface quality, as well as further processing properties. The GEOPLAST formwork system is widely used due to its undeniable advantages:

- low weight of panels allows manual installation and transportation to/on a construction site without using a crane or other lifting equipment;
- despite its lightweight, the formwork made of ABS plastic is durable enough and can withstand the load of up to 80 kN/m²;
- low adhesion of concrete to plastic makes it possible to obtain a high-quality surface of a finished structure, use less lubricant and quickly clean the formwork with water without the use of detergents;
- with proper operation, the turnover of the framework system is at least 100 cycles, and after the expiration of a period of service, the formwork can be sent to be recycled [15-17].

When designing a formwork, the task of paramount importance is to determine the loads it will be exposed to. In general, the load on the formwork system is divided into two groups: vertical and horizontal. The first includes loads arising from the formwork's weight, reinforcement and concrete mix weight, and loads created by vehicles and the workforce. Vertical loads occur when concreting horizontal monolithic structures, including the inclined-horizontal ones: beam and ribbed-slab floors, domes, spheres, shells, arches, bridges, overpasses, and other superstructures. The second group includes wind loads and the maximum pressure of the concrete mixture [14]. All of the above loads are not as significant as the loads exposed during concreting since it is when laying a concrete mixture that the greatest loads on the formwork occur. The most critical loads are horizontal loads caused by the lateral pressure of a concrete mixture, for which the formwork of vertical structures is calculated [18-20].

The maximum pressure of a concrete mixture on the formwork is assumed to be equal to the hydrostatic pressure with a triangular epure (Fig. 2 a):

\[ P_{\text{max}} = \gamma h \]  

where \( \gamma \) is the specific weight of a concrete mixture, kg/m³; \( h \) is the concreting height, m.

The resulting pressure is equated to the epure area; that having been said, the safety factor should be taken into account, which is assumed to be equal to 1.3 when calculating the lateral pressure of a concrete mixture. Then the horizontal pressure on the formwork will be determined using the following formula:

\[ P = 1.3\gamma h^2/2 \]  

Having determined the maximum possible pressure of an expanded polystyrene concrete mixture for a formwork, we then need to select its section. When selecting the section of a formwork, one needs to consider the loads, the structural design, and the conditions:
a) strength:

\[ W = \frac{M}{R} \quad \text{or} \quad \frac{bt^2}{6} = \frac{M}{R} \]  

where \( b \) is the width of the formwork panel; \( t \) is the thickness of the formwork panel; \( M \) is sectional modulus of the formwork section, kg\* m; \( R \) is the design resistance of the formwork material, kg/m;

b) rigidity:

\[ J \geq \frac{kql^4}{Ef} \quad \text{or} \quad f = \frac{Pl^3}{EJ} k \leq \frac{1}{400} \]

where \( l/400 \) is the maximum allowable deflection value; \( k \) is the coefficient taken according to Table. 30 SP 16.13330.2017 depending on the loading diagram; \( E \) is the elastic modulus of the formwork material; \( J \) is the inertia couple of the formwork section, determined using the formula:

\[ J = \frac{bh^3}{12} \]

Given the height of the formwork panel \( h = 3 \) m and width \( b = 1.2 \) m, we conclude the thickness of the formwork to be \( t = 40 \) mm as a result of simple calculations using formulas (1)- (5). Further, having made sure that condition (4) is met, we conclude that the rigidity of the formwork being designed is ensured since the resulting deflection value \( f = 0.05 \) mm does not exceed the maximum permissible value equal to \( l/400 = 3000/400 = 7.5 \) mm.

Among other things, when designing a formwork model following the requirements of the Russian standard 34329-2017, high quality of a concreted structure should be ensured, as well as:

- stability of geometrical shape and size when exposed to installation, transport, and technological loads;
- the design accuracy of the geometric dimensions of monolithic structures and the specified quality of their surfaces;
- maximum turnover and minimum cost per turnover;
- minimal adhesion to a set concrete;
- the minimum number of elements' nominal sizes depending on the nature of monolithic structures;
- the possibility of fixing embedded parts following the design position and design accuracy;
- ease of manufacture and the possibility to use mechanical operations and automation during installation;
- quick-disconnect of connecting elements and the possibility of fixing the gaps that appear during long-term operation;
- minimizing material, labor, and energy costs during installation and dismantling;
- ease of repair and replacement of failed elements;
- tightness of forming surfaces.

The proposed ABS plastic large-panel formwork diagram is shown in Fig. 2 b.
The large-panel formwork designed for erecting expanded polystyrene concrete walls is rectangular panels made of ABS plastic of a size of 3000 x 1200 x 40 mm. To ensure the necessary strength and rigidity, the outer side of the formwork is made cellular with a large number of longitudinal and transverse stiffeners placed in increments of 300 mm. The inner surface of the formwork panel touching the concrete being laid is smooth, which makes it possible to achieve high quality of a finished concrete surface. Holes for clamps are provided at the ends of panels. Handles made of specially developed durable material – polyamide are used as clamps. By simply turning the handles 90°, one ensures a reliable and pressure-tight joint of the panels. Panels can be adjusted and fastened in a vertical position with the help of braces. One should anchor the panels to the floor to prevent possible lifting of a formwork. Using such a large-panel formwork rather than a prototype makes it possible to significantly reduce the manpower effort and duration of work on the formwork of structures. At the same time, this large-panel formwork model was developed to as much as possible preserve the main advantages of the GEOPANEL small-panel formwork system, as well as to provide for manual installation since the weight of the panel being designed reaches only 27 kg. Thus, the large-panel formwork model developed meets the requirements of the Russian standard 34329-2017 for the designs of formwork systems.

*Technology for erecting monolithic exterior walls made of expanded polystyrene concrete.*

The proposed technology for concreting monolithic walls made of expanded polystyrene concrete mixture provides for the use of large-panel plastic formwork and foam concrete mixing units.

When using the developed large-panel plastic formwork, the installation procedure is simple, and there is no need to use a crane and other lifting equipment.
Polystyrene concrete mixture is supposed to be made during construction production using a mobile foam concrete mixer SPBU-150 Lux. The foam concrete mixer should be placed in a specially designated zone of a construction site with a slope of no more than 20° with convenient passages provided for loading, inspection, and repair activities. The main advantage of the foam mixer is the ease of combining the functions of three units: a concrete mixer, a foaming machine, and a concrete mixture feeding pump. At the same time, the unit has small overall dimensions (600 × 800 × 1400 mm), making it possible to carry out work in a tight working space or place the unit indoors. In addition, the foam concrete mixer SPBU-150 Lux can supply concrete mixture over considerable distances: up to 30 m vertically and up to 100 m horizontally, which is clearly its advantage.

The proposed diagram of concreting monolithic exterior walls made of expanded polystyrene concrete is shown in Fig. 3.

![Fig. 3. Schematic diagram of erecting monolithic walls made of expanded polystyrene concrete in large-panel plastic formwork](image)

Installation of monolithic enclosure structures using expanded polystyrene concrete mixture involves: installing and binding the wall reinforcing bars on the project; installing the formwork tiered on each floor mounted and clamped; installing scaffolds; producing expanded polystyrene concrete mixture (composition per 1 m³: Portland cement – 400 kg, sand – 120 kg, water – 280 l, superplasticizing admix "Glenium 51" – 2.4 l, foaming additive "Penetron" – 1.35 l, grinded expanded polystyrene – 10 kg); laying expanded polystyrene concrete mixture into the formwork; maintaining the expanded polystyrene concrete; dismantling the formwork.

A one-story building with overall dimensions of 9.6 × 9.6 m was taken as an example for calculating labor costs for the construction of monolithic enclosing structures (h = 3 m) made of expanded polystyrene concrete. In this example, the estimated cost of erecting monolithic walls made of expanded polystyrene concrete at the current price level as of the IV quarter of 2022 amounts to 354,784 thousand rubles. The calculated labor and machine
time costs for the construction of 46 m³ monolithic polystyrene concrete structures amounted to 163.76 people.*h and 27.36 units.*h, respectively.

4 Conclusion

1. A model of ABS-plastic large-panel formwork for concreting walls made of expanded polystyrene concrete mixture is proposed. The model is rectangular panels made of ABS plastic of a size of 3000 x 1200 x 40 mm. Recommendations are given to ensure its rigidity and strength.

2. A technology has been developed for erecting building enclosing structures made of expanded polystyrene concrete using large-panel plastic formwork and a mobile foam concrete mixer SPBU-150 Lux directly on a construction site, with a work sequence described.

3. Technical and economic indicators for erecting monolithic walls made of expanded polystyrene concrete of a volume of 46 m³ are given: The cost amounted to 354.784 thousand rubles, and the labor intensity and unit capacity are 163.76 people.*h and 27.36 units.*h, respectively.

References

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