The Technology of Installation Using Pneumatic Inflatable Formwork

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Abstract. The article is devoted to the current topic of fast-assembled buildings, the analysis of existing technologies, including the use of pneumatic formwork, allows installation both in the urban environment and in special conditions. A crane-free installation technology using pneumatic formwork is proposed, followed by filling the inter-deck space with foam material based on Quad Core.

1. Introduction
The ongoing global cataclysms and events directly related to Russia, such as large-scale floods in the Irkutsk region and Primorsky Krai, and the recent pandemic, have once again confirmed the declining relevance of the development of technologies that allow fast-assembly installation.

It should be taken into account that more than 60% of our country's territory is located in the Northern latitudes, in permafrost zones, one of the most difficult areas for construction and human habitation, and the development of mining and processing industries requires creating conditions for a comfortable stay of people.

Installation technologies that allow to erect buildings and structures in the shortest possible time both in difficult natural and climatic conditions and in urban development are in high demand. There are several well-known technologies, leaving on two main areas, that of the building erected at the construction site and assembled from factory-made modules: the first category is in turn divided into built-in removable and non-removable formwork, including the hydraulic and air-supported formwork, the second includes the frame, panel, block and container construction (Fig.1).

All these technologies have their advantages and disadvantages.
2. Methods

The main ways to reduce construction time: unification, modularity, reduction of technological operations, optimization of geometry; however, the subsequent operational component, the absence of "cold bridges", the creation of a closed loop that reduces energy consumption is also an important factor.

The most widespread use of modular or large-scale buildings and structures, which allows almost all-season installation. In Omsk, a medical hospital for patients with coronavirus was built from large-panel elements together with finishing in a period of just over 50 days; however, it is necessary to take into account the significant disadvantages of this technology: high transport costs, the need to use complex crane equipment, the inevitable formation of cold bridges in the interstitial seams, and subsequent operating costs.

No less common method is frame housing construction. The progenitor of frame housing construction can be considered a half-timbered house construction in Germany known since the beginning of the 17th century. Frame housing construction allows the widest choice of execution of elements of a framework and external wall designs, from reinforced concrete to metal and wooden, filling of external walls with a
brick, installation of hinged wall panels, both reinforced concrete, and sandwich panels, and the last ecological direction in the European countries OSB panels.

In Rostov-on-Don, this technology made it possible to build a hospital for those infected with coronavirus in 56 working days.

The advantage of frame housing construction is significantly lower, compared to monolithic and fully assembled buildings, the weight of the resulting structure, the ability to implement almost any shape, with minimal shrinkage. The most unusual spherical building with a fully assembled metal frame and hinged wall panels made of vacuum double-glazed Windows was built in Astana. Lahta center is a vivid example of frame housing construction.

In the Nordic countries and in Germany popular frame construction from concrete - wood composites and the spatial structures made of LVL beams and CLT, meeting the increased requirements of efficiency, speed of installation, and cost reduction. One of the world's tallest wooden buildings, the Mjos Tower was built in Norway, and the key factor here is the use of factory-made LVL timber, which significantly reduces the time and cost of construction and subsequent operating costs.

But these technologies are difficult to apply in the Arctic, due to high transport costs, the need for expensive crane equipment, and wooden housing construction in Russia is limited by fire regulations.

An alternative to frame construction can be the grid construction technology developed by V. G. Shukhov. This technology will further facilitate the frame of the building, thereby reducing the load on the foundation, and reduce the material consumption and cost of construction, allowing for crane-free construction.

For all - season buildings and structures with a long service life, taking into account transport costs, the best option for spatial rigidity and specific values of heat loss is thin-walled spherical and extended structures, full snow load $p_s = 500 \text{ N} / \text{m}^2$ – the minimum ratio of area to internal volume, good work on compression and deflection. Dome coverings also contribute to the natural clearing of snow when exposed to wind. There are several modifications of them, in removable and non-removable forms: structures, shells, pneumatic structures. A good example is the Arctic Shamrock.

Pneumatic structures made of rubberized fabric or polyvinyl chloride awnings, air-supported or air-framed with an internal, usually metal frame - the easiest way to get dome shapes. The technology requires minimal use of construction equipment and is easy to deliver and install.

And here, as always, the army became in the first row, offering the developed technologies and proven methods of installation, in the shortest possible time, these are hydraulic formwork with the application of a concrete mixture shotcreting method on the inflated formwork (the method was developed in 1980 at the Leningrad Military Construction School) and nanoconcreting (Engineers of the Military Training Center of the Far Eastern Federal University).
The most widely used cylindrical formwork (Fig. 2).

**Figure 2.** Pneumatic Formwork:

a) variants of pneumatic formwork; b) a Section along the line 1-1 demonstrating the method of raising the formwork; c) load distribution scheme: 1 – domed structure of the petal type; 2 – cylindrical structure with apsidal completion; 3 – extended cylindrical structure; 4 – contour of the formwork; 5 – entrance gateway zone; 6 – foundation element; 7 – air heater.

The disadvantages of this method include the need for constant air pumping and low load-bearing capacity during the period of concrete strength gain.

3. **Results and discussion**

In order to reduce the cost of installation, a technology was developed that involves the use of fixed pneumatic formwork, high strength, not less than 1100 g / m², based on a thermoplastic material.

4. **Main stages of installation:**

1. Installation of a Foundation system with protruding pivoting elements and a Central support column (core-which allows not to use additional connections and gives the frame additional rigidity), which will be supported in the future by semi-arches.

2. Large-scale assembly in the ground position of planar trusses (semi-arches), with a strong adhesive connection in the lock (Fig.3), attachment of the crate and stabilizing cables, which allow to redistribute the load and reduce the cross-section by pulling. Layout of semi-arches in the pre-design position, and hinged-movable fastening on the foundation shoes. Installation begins with the extreme segments, and additional adjustment is made using hydraulic jacks and tension wheels.

**Figure 3.** Tensioned oblique lock with spikes, for connecting elements.
5. Crane-free installation using winches. Lifting semi-arches with lathing elements to the design plane alternately, in a counterclockwise direction (Fig. 4).

4. Fixing the ridge connections, and if necessary, removing the mounting column, which significantly increases the useful area.

6. Sliding and fixing the fabric fixed upper part of the formwork, and the layout of the internal form. The coating is calculated in advance, sewn together with subsequent sizing of the seams.

7. Installation of the air supply unit and injection of air to give the desired shape, processing by aeration of the pneumatic formwork with a special hydrophobic composition. (For example, Denstop PU 650, total consumption 2.2 kg / m², increasing elongation at break up to 400%, tensile strength 15 MPa, and having an operating temperature from -60°C to +150°C.) The coating can be applied even at low temperatures. Access to the interior of the facility is provided by tightly closed airlocks (Fig. 5).

Figure 4. Structure of the dome building frame:
1 – support column or reinforced concrete core; 2 – lifting winches; 3 – semi-arch; 4 – lathing element.

Figure 5. Installation of pneumatic formwork shells: 1 – support column or reinforced concrete core; 2 – flat semi-arc; 3 – inner shell, with the elements of the pipeline removed for air injection; 4 – external tension shell; 6 – foam insulation Quad Core; 7 – high grillage; 8 – support rotary elements of the foundation shoe.
7. Filling the inter-deck space with nanomix, which reliably connects all the elements of the structure. The mixture can be filled even at negative temperatures, up to minus 5 degrees. This composition will help to maintain the strength and durability of structures built in the cold, without increasing the cost of the technological process.

The decks are filled initially about a little more than half, the foaming process lasts no more than 8 minutes, and after lowering the mass, solidification occurs in 24 hours, but the final required strength of the material in low temperatures is achieved only after 28 days.

Unlike previous developments, this mixture contains less foaming components, which were replaced with ash waste from energy production and sand crushing screenings, it is possible to use calcined and sifted local soil, this reduces the cost of 1 m\(^3\) composition, and reduces the fire hazard.

To reduce energy consumption, QuadCore material (SP 131.13330.2012) was used as a binder in the wall material, which has significantly higher thermal insulation properties (\(\lambda = 0.019\) W/m. K), which has a fire hazard class Ko (15), the material has high adhesive properties, which will allow it to be used as a damper and significantly increase the perceived loads of the frame, which makes its use more economically profitable.

When manufacturing structures directly on the construction site, it is necessary to take into account several indicators: gas-forming agents, the quality and process of mixing components to achieve uniformity of the mixture, and the use of sodium mixtures as accelerators. Indicators of the required thickness of wall structures based on the thermal resistance of the main non-autoclave materials capable of obtaining a reliable adhesive connection with frames made of wood-plastic materials are presented in table 1.

**Table 1.** Ratio of thermal conductivity coefficients and the required thickness of the outer fence.

| Name of the material                               | Coefficient of thermal conductivity W / m°C | Required wall thickness, m |
|---------------------------------------------------|--------------------------------------------|-----------------------------|
| Ground concrete (on clay compositions)             | 0.52                                       | 2.86                        |
| Aerated concrete based on TPP resins               | 0.14                                       | 0.77                        |
| Ground concrete based on PIR (polysicyanurate foam)| 0.062                                      | 0.341                       |
| Ground concrete based on Quad Core                 | 0.026                                      | 0.143                       |

**Note:** The required heat resistance for walls in the Al-Juhani area was: 5.5 R, m\(^2\) · °C/W (SP 131.13330.2012 Construction climatology) A study on gruntubelem provided by the firm "Instrotech LTD".

The maximum possible deflections are calculated depending on the cross section of the upper half-arch belt when the LVL bar and QuadCore acting as a damper work together, taking into account that the angle formed by the half-arch allows you to regulate the accumulation of snow masses, reducing pressure, but increasing wind stresses (Fig. 6).
Figure 6. Distribution of deflections of the upper belt of the semi-arch depending on the length of the span and the size of the cross-section.

Unlike previously existing technologies: formed monolithic structure made of foam material based on a QuadCore with the use of the filler calcined and sieved soil (decreasing the flammability of the structure), increases the thermal resistance, required wall thickness; the damping ability of QuadCore material to wood, and its much lower density compared to concrete, reduces the cross-section of semi-arches, and thereby the material consumption, which greatly reduces the cost of shipping; the crane-free installation method significantly reduces the labor intensity and duration of works.

5. Conclusions
1. Compactness of structural elements in the disassembled position.
2. The use of lattice structures and stabilizing cables reduce the weight, increase the load-bearing capacity.
3. Soil based on QuadCore binder, reduces the load on the base, thermal conductivity of external structures, non-autoclave hardening, allows the production of wall structures directly on the construction site.
4. Not require an expensive crane equipment (installation using winches and scaffolding).
5. Very short installation time. Planar spatial structures that are pivotally fixed in the places of supports are easily installed in the design position, eliminating the time-consuming process of adjustments. Based on the analytical calculations, the construction of the ground part of the object up to three floors, taking into account the preliminary consolidation Assembly, and technical breaks for the hardening of the material will not exceed 35 shifts.

The use of this technology will significantly reduce the final cost of the product, allowing you to meet the maximum pace of construction, which, we hope, will make it possible to widely use this technology.

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