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TECHNOLOGIES FOR FAST ECONOMICAL CONSTRUCTION OF RESIDENTIAL BUILDINGS

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ABSTRACT

A new approach to the development of innovative technologies in the construction process for the rapid construction of individual houses in a simplified way using "dry" assembly industrial sand HIV-panels was researched. Using modeling methods and subsequent multi-criteria provides the optimization of technological solutions. The information-technological model of the industrial construction system is presented in a mathematical form, which makes it possible to carry out an accurate analysis of defects in pre-fabricated module buildings and to implement accelerated assembly technology. Key importance belongs to the following: adaptability of project solutions to streamline production, accuracy of assembly and a regulated pace of assembly operations on the construction site by means of transportable small-size equipment.

Keywords: sandwich elements, pre-fabricated transportable buildings, construction, dry mounting, coupling-sleeve node.

INTRODUCTION

In 2015 the authors researched a new approach to the development of innovative technologies in the construction process for the rapid construction of individual houses using the simplistic "dry" assembly method along with industrial sandwich panels. The object of the research is to study the process involved when constructing individual houses by way of the installation of industrial sandwich panels. Thus, this house type, known as cottages, which is a special type of construction projects with a high degree of prefabrication, allows for faster installation than traditional methods using stone building materials - brick, concrete, reinforced concrete, etc. The subjects being researched are the parameters of the technological processes of constructing individual houses built using industrial sandwich panels. The goal is to reduce the overall complexity and cost of construction in Russia.

Developments in the industrial construction process of low-rise buildings under modern conditions is defined by the large demand for residential buildings on the outskirts of cities and the necessity for quick construction of residential townships for the military and people living in regions with specific and harsh climatic conditions. The solution to this urgent problem can be achieved through the use of pre-fabricated modules with a high degree of readiness, improved thermal insulation and consumer quality.

The development of this trend is hindered by the insufficient preparation in production and lack of relevant technological procurement.

Various methods of component-by-component assembly, including the stage-wise assembly of the building frameworks, roof and load-bearing elements of floors and decks, have certain drawbacks related to the specific climate in the North, large labor consumption, long periods of assembly, and the need to use heavy transport and lifting equipment.

Many researchers consider the main drawback of variant-based projecting of buildings and facilities (in particular, technologies for structure assembly) to be the selection of a single variant based on the pre-defined sequence of processes.

A significant input into the developing technologies for pre-fabricated buildings in harsh climatic conditions was made in the numerous research works.

Substantiation of optimal organization-technological solutions, selection of optimal technologies for volumetric-module, pre-fabricated low-rise buildings, as well as an investigation into technologies for constructing such buildings in various conditions are presented in the works by Anderson *et al*., 2007, Staib *et al*., 2008, Rounce *et al*., 1998, Wang *et al*., 2007, Head *et al.,* 2001, Swamy *et al.,* 2001, Knaack *et al*., 2012, Allen *et al*., 2004, Nadim *et al*., 2010, Day *et al*., 2011, Afanasiev *et al*., 2007 Fudge *et al.*, 2011, Lawson *et al.*, 2010. Some authors place the central point of costs onto distant residential objects and industrial and public buildings.

A unique technology was devised by the Chinese construction company Broad Sustainable Building (BSB) who developed and improved a unique technology for the extremely quick construction of buildings from ready-to-install modules, which allows for a 5-star 30-level hotel building to be erected in just 15 days. The construction site is supplied with pre-fabricated modules: load-bearing steel pillars, wall and floor panels with electric wiring, water pipes, floor covering and LED lighting already installed in them. Modules are connected to each other using a function similar to “LEGO”; staircases and outer walls made from 15-cm thick multi-layered material and dual-pane windows are installed. Typically there is a huge “refrigerator” functioning on natural gas installed into the

ARPN Journal of Engineering and Applied Sciences

building. This 3,500-ton unit forms a centralized conditioning and ventilation system capable of cooling 500 thousand cubic meters of residential spaces.

METHODS

A variety of factors are taken into consideration during the complex methods of research in the following way: a system analysis and synthesis of innovations for construction and high-speed construction; patent research and methods for solving inventive tasks during the latest 30 years; theoretical and experimental research of technological parameters of a half-storey on a prototype model (scale 1:20), on full-scale models of particular units (scale 1:1) and in factory conditions; statistical analysis and use of the theory of probability for chronometric and photogrammetric sensing data processing; expert evaluation of the buildup adaptability over the 3D model to streamlined production; technical-economical assessment of a new technology efficiency (Adam, 2001, Bad'in, 2013, Sychev, 2015).

As an efficiency criterion for the system of industrial half-storey construction, the complex cost index (C_c) is used, which is the sum of time consumed and resources used during manufacture (C_m), transportation (C_{tr}) and the assembly of pre-fabricated structures (C_a), $C_c = C_m + C_{tr} + C_a \rightarrow \min$.

The information-technological model of the industrial construction system is presented in the form of composite functions:

$$\left.\begin{array}{ll}\sum_{i=1}^{n} Q(C_c) \rightarrow \min, & C_m = f_1(l_p, b_p, m_p, N_s, P), C_a = f_3(l_p, b_p, m_p, Q, T) \\ \sum_{i=1}^{n} T(C_c) \rightarrow \min, & C_{tr} = f_2(l_p, b_p, m_p, N_s, L, n)\end{array}\right\}$$

l_p , b_p , m_p	length, width, weight of panels, respectively
N_s	number of standard sizes of structure elements
L	distance from the factory to the construction site
n	number of structures
P	production capacity of the technological line
$Q(C_c)$	labor consumption requirement
$T(C_c)$	duration of assembly for the volumetric block

ANALYSIS

Improving the technologies used in the construction of low-rise buildings from factory-made modules improves the safety and quality of buildings while decreasing labor and time consumption during construction on the basis of developing optimal methods of technical diagnostics and logistics for constructing modular buildings.

Technology of Accelerated Assembly for Half-Storeys from Aggregated Unified Sandwich Panels

A completely new technology has been developed and substantiated for the accelerated assembly of industrial pre-fabricated half-storeys from unified light-weight metal structures in the form of sandwich panels; it ensures quick and accurate assembly using small-sized transportable equipment: a multifunctional hydraulic hoist-manipulator and movable scaffold in the form of a collapsible framework jig.

An assembled roof for the half-storey type construction consists of two types of panels: straight-shaped and angular-shaped; they incorporate a load-bearing framework in the form of cold-formed thin-wall T-shaped steel girders.

In essence, the accelerated pre-fabricated technology for assembling half-storeys is as follows: at the assembled level, on the load-bearing walls along the perimeter of the building, a concrete belt is created, where corner panels are installed on anchors. The framework jig (movable template) is used to prevent structures from folding and deforming.

Further rows of panels are fixed to these panels with bolts and self-tapping screws. Panels are put together alternately, which ensures stiff (not pin-edge) panel fixture.

It should be noted that such technology makes it possible to transport elements of the building in their assembled form without using high-capacity machinery. For example, if the building is 12 meters wide, 5 angle and 10 straight-line panels are used, with the half-storey height being 3.65 m.

Technical-economical efficiency of this technology is manifested in decreasing the cost of 1 m^2 approximately by 22.8 %, labor consumption by 48.2 %, assembly duration by 1.5 times as compared to traditional component-by-component technology. Integral assessment of the adaptability to streamlined production on the basis of differential, generalized indexes was 0.82, which indicates a high level adaptability to streamlined production and efficiency of assembling half-storeys from LMC-panels (light metal construction). The resource and energy-saving technology of accelerated assembly for half-storeys from unified sandwich panels is characterized by the high degree of accuracy of the assembly process, the possibility of quick disassembly and selective repairs.

ARPN Journal of Engineering and Applied Sciences

Technology of Assembling Buildings and Half-Storeys from Completely Ready Block-Modules

Pre-fabricated module buildings (PFMB) are assembled from volumetric unified elements – block-modules pre-fabricated at the factory, including the in-door engineering networks to ensure the required physical-mechanical properties of structures are maintained: stability, rigidity, strength, stable geometry of modules during transportation and assembly. Volumetric-spatial block-module is an integrated system developed by technologists, architects, designers and other specialists; it has optimal parameters of cost-efficiency, adaptability to streamlined production, transportation, assembly and disassembly, convenience and safety of operation.

The investigation was based on continuous monitoring of PFMBs during various stages of construction, studying improved construction technologies for low-rise buildings from block-modules and on the optimal methods of technical diagnostics and logistics for constructing module buildings.

A 3D model of the pin-edge and joint structure was built using a computer-aided design system: Microsoft Project and AutoCAD, so as to align the model within the volume of a half-storey block. The above-mentioned system also includes the organization-technical component (human resources, a complex of technical, software and other means).

Construction components should be produced on a multifunction assembly bench fitted with all the required technical and technological equipment.

Experimental works confirm that, if the assembly crane with coordinate-step mechanism and stiff cross-bar is controlled remotely, the assembly time is 1.5 times shorter and the crane productiveness increases by 40-60 %.

For example, a two-storey 10-apartment residential building consisting of 28 volumetric pre-fabricated block-modules sized 20.5 m x 24.0 m, complete with a technical cellar and with each apartment having a 2.5 m high ceiling, with a build in attic and sloping roof. The foundations of the building – tape-form, made of concrete, with longitudinal and transverse walls on which volumetric block-modules rest with their lower surface along their entire perimeter (figure-1).

The volume of the building is V = 3225 m^3; area F = 976 m^2; number of storeys - 2; weight 20 t.

The outer surface of the module (building) is a combined structure with thermal insulation. Module joints are welded. Joints are packed on the outside contour by rubber and glue. The degree of readiness is 95%.

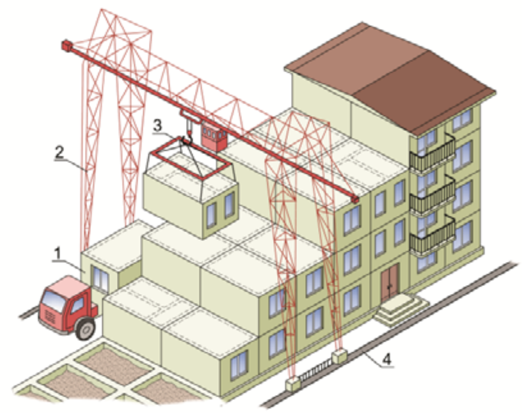

Figure-1. 3D model of prefab modular building erection.

Technology used in the erection of individual houses using the "dry" assembly method with sandwich panels sized 1.2x3.6 meters having 95% degree of prefabrication on the basis of flexible "coupling-sleeve" nodes

The developed technology for the installation of bearing components in individual houses includes a horizontal bearing element, vertical bearing elements in the form of racks and panels and a foundation cushion with plates. The vertical elements are attached to at least one spike with the horizontal load-bearing elements fixed to the coupling. The dowel is installed in the clutch or with its aligned or misaligned pins. The covering panel and floor couplings are designed for mounting studs on the top and bottom of the coupling. Couplings are constructed in a barrel-shape with a vertical slot the full height of the coupler, which forms two elastic petals. The coupling walls are provided with holes for the pins to make installation of the panels easy through a means of lifting. A spike is made in the form of a barrel liner. This clutch is made with vertical slits on its entire height forming elastic petals. Seals on the joint between the horizontal and vertical panels occur automatically due to them being fixed to the mounting on the ends of the panels in two layers. The perception of the connection nodes for alternating loads in the construction of individual houses are due to the interaction between the outer barrel surface of the stud part with the inner barrel surface of the coupling. Tight compression is ensured by the fact that as a result of the presence of full height vertical slots in the clutch, forming two elastic petals, which stand up under the action of the barrel-shaped sleeve of a stud when mounting a horizontal support member on the vertical support plate after the connection of the node which is seeking to regain original shape. As a result, the petals fold around the clutch and at least one spike is tightly pressed against the petals when the load is directed upwards, i.e., a reliable connection of sandwich panels in an individual residential house.

The coupling is made from steel which is formed into a barrel-shape. The spike is also made from steel in the form of a barrel liner. The clutch and spike have vertical full height slits. A portion of the outer surface of the stud part interacts with the inner surface of the coupling

Thus, the proposed technological solution differs from the known fact that, for the purpose of reducing the complexity and cost of installation of individual houses due to the perception of alternating dynamic loads, the coupling is made barrel-shaped with a vertical slot the full height of the coupler, and the thorn in the form of a barrel liner. The clutch and the liner are made with vertical slits up their entire height, and a portion of the outer surface of the stud part interacts with the inner surface of the stud which in turn interacts with the inner surface of the coupling.

It is proven that the technology used in the installation of individual houses from large industrial sandwich panels (1.2×3.6 meters) allows significantly reducing the complexity and cost of installation as compared to the traditional construction technologies of low-rise houses made from brick and reinforced concrete. It is established that the main leading construction operations of the proposed technology are the processes of "dry" assembly using large sandwich panels of full factory readiness with the use of standard units of compounds based on flexible node-type coupling-sleeves, gaskets, silicone gaskets and flashings (Kazakov, 2015). It is revealed that the auxiliary building processes in the developed technology are preparatory, insulating, finishing and quality control operations. It is proven that during the actual erection of three cottages in the village of Severskiy, Leningrad region, all theoretical bases for the proposed technology have been confirmed. In the erection of houses it is only possible to implement the lower level of three installers. There is no need for "wet" processes, welding and the embedment of components and joints can be effectively installed at any time of the year and with high production. Their analysis confirmed the high levels of adaptability of all the construction processes.

CONCLUSIONS

a) An optimal variant has been developed as a design-technological solution for half-storeys from linear and angle unified sandwich panels with standard sizes 100×100×20 cm, 100×91×20 cm and weight up to 35 kg.
b) Using software, an algorithm has been developed for the variant-wise projecting of the buildup of half-storeys from block-modules with a 95% degree of readiness.
c) Technical-economical efficiency of the technology for the buildup of half-storeys is manifested in decreasing the cost of 1 m^2 by 22.8%, labor consumption by 48.2% and assembly duration by 1.5 times as compared to the traditional component-by-component technology.

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