Block-span method of roofing structures assembling

Vladimir Kocherzhenko¹, Lyudmila Suleymanova¹* and Igor Ryabchevskiy¹
¹Belgorod State Technological University named after V.G. Shukhov, Belgorod, Russian Federation
*Corresponding author’s e-mail: ludmilasuleimanova@yandex.ru

Abstract. The currently used block-conveyor assembling method requires costs for creating an area for blocks conveyed assembly and applying special assembly-and-lifting equipment and tooling; the erection of reinforced-concrete structures by large-sized prefabricated blocks is not possible without a special cross frame and guide casing, imitating a truss structure. The purpose of the research is designing a block-span method of assembling reinforced-concrete roof structures for one-storey industrial buildings, which would allow increasing the labor productivity, ruling out the usage of cranes with increased lift capacity for lifting blocks, reducing the scope of work at heights and increasing the building safety. The developed block-span method of mounting reinforced-concrete roofing structures with secondary trusses implies the assembling of an enlarged roofing block at ground level in the span between previously erected columns, through the full length and width of the span. The block includes secondary trusses, trussed rafters and roof slabs. The block is assembled on the backing 0.5 m high and 0.4…0.5 m off the center line and the width axis of the building. A block is a geometrically stable structure; all joints are connected by welding embedded items. A block is lifted by simultaneous activating of electric hoists. The block is lifted higher than the columns, moved to permanent position and put on top of columns by means of electric hoists. So, the developed method of roofing assembling allows reducing labor intensity by 1.6 times and duration by 1.4 times.

1. Introduction
In the total volume of labor costs and machine intensity for the construction of a reinforced concrete frame of one-story industrial buildings, the cost of installing roof elements is about 60 %, i.e. are predominant [1-6].

For many years, the main method of assembling metal and reinforced concrete structures of the roof remained the method of element-wise assembly, which provides for the installation of roof secondary-trusses, roof trussed rafters and roof slabs using mounting cranes [7-9]. This method has a number of significant drawbacks: high machine intensity, low productivity, a large amount of steeplesjacking, hardly feasible quality control of installation work at a height [10-14].

Block-conveyor reinforced concrete roof structures assembling for one-story industrial buildings is well known [15]. However, this method has a limited scope (coverage should be more than 25 thousand m2), requires the creation of a conveyor area for assembly of roof blocks, a storage area and the use of special mounting lifting equipment and accessories.

The large-block installation of incomplete reinforced concrete roofing structures [10] provides for a single trussed rafter, cover slabs and a jig-traverse in the block. At the same time, the jig-traverse takes all mounting loads and ensures the geometric immutability of the block during its lifting-feed. This
method allows you to increase productivity and reduce installation time. However, this method requires the use of a special jig-traverse and a ground conductor, which is a frame and a truss that imitates a rafter structure. For lifting a reinforced concrete block to the design level, a heavy-duty mounting crane is required as a rule.

The aim of the study is to develop innovative structural and technological solutions for the block-span installation method for reinforced concrete structures for one-story industrial buildings roofing, which allows to increase labor productivity, ensure the safety of work and eliminate the disadvantages of the above installation methods.

In this case, the authors solved the following problems:
- to develop the design of the span length cover block, the assembly of which is carried out at ground level of the construction site, while it is necessary to ensure geometrically stable construction and rigidity of the roofing block;
- provide for a specific location of the construction of the building block, allowing unhindered lift to the design level;
- to develop a method for lifting a building block without the use of self-propelled cranes, for lifting structures onto columns using electric hoists, chain hoists and ropes;
- to provide for the placement of bypass blocks and the stock of ropes through them so that the building block evenly rises smoothly while turning on the electric winches and is under uniform, symmetrical loads close to operational at the same time;
- to propose structural and technological solutions that ensure the lifting of the building block of the roofing 200...250 mm higher than the column, followed by lowering it onto the columns.

2. Methods

To solve the tasks, the assembly of the enlarged roofing unit is carried out for the entire length and width of the span (Fig. 1 and 2). Moreover, on backings 2 with a height of 0.4 m roof trusses 1 are installed with an offset of one of the longitudinal axes by 0.45 m, providing a gap of 0.05 m between the side face of the column and the side surface of the secondary truss [16, 17].

![Figure 1](image-url)

*Figure 1. The design of the mounting block, the installation diagram of electric winches, bypass blocks and rope reeving: 1 – secondary trusses; 2 – backing; 3 – trussed rafters; 4 – roof slabs; 5 – openings in the roof slabs for the passage of columns; 6 – bypass blocks installed with a clip above the column; 7 – ropes-traction; 8 – bypass blocks installed on the secondary trusses; 9 – electric winch; 10 – tackles; 11 – columns*
Along the span, the secondary trusses \( I \) are also offset relative to the transverse axes by 0.45 m to provide a gap of 0.05 m between the faces of the columns and the lateral surface of the secondary truss. To form a continuous system from the secondary trusses \( I \), their joints are welded by electric welding.

On the secondary trusses \( I \), with the help of self-propelled cranes, the trussed rafters \( 3 \) are installed. On the trussed rafters \( 3 \), the roofing slabs \( 4 \) are mounted. The extreme slabs \( 4 \), lying behind the columns \( 11 \) in the adjacent span, are made with openings \( 5 \) for passing through the mounting block of the columns \( 11 \).

In order to reduce the volume of construction and installation works at a height, cement-sand screed, vapor barrier, insulation (according to the project), screed and roof are arranged on the roof plates. If necessary, engineering communications are passed through in the inter-farm space. The process of lifting a building block is carried out by simultaneously turning on four electric winches installed at the ends of the span (Fig. 1 and 2).

The block is raised above the columns by 200...250 mm due to the bypass blocks \( 6 \) mounted above the column heads due to the bypass blocks \( 6 \) mounted above the heads of the columns \( 11 \) using metal cages \( 12 \) (see view A–A). Then, with the help of jacks or winches, the block moves in two directions: along and across the span above the columns and gradually lowers onto the columns in the design position.

As is known [18], depending on the possible and appropriate degree of combining construction work, installation of structures and technological equipment, one-story industrial buildings are constructed using open, closed, coincident or combined methods. These methods reflect different degrees of combination and sequence of work, which should always be taken into account when organizing the installation of building structures.

According to the open method at first all work on the construction of the underground part is carried out at the installation site, after which the structures of the ground part of the building, technological equipment, and pipelines are mounted and finishing work is performed.

Using the closed method, at each installation site, earthworks and foundations are first carried out only for the building, after which the building frame is mounted. At the end of installation work, foundation pits are dug inside the building frame, foundations are built for built-in structures and technological equipment, and then built-in structures and technological equipment, pipelines are installed, and then finishing work is carried out.
As for the combined method, a common foundation pit for the underground facilities, foundations for the building and equipment is first excavated. Concreting of foundations for equipment and other underground work is combined with the installation of the building frame.

All of the above installation methods are applicable for element-wise installation of a building frame. And the block-span method of installation of roof structures developed by the authors is well combined with the closed method in combination and sequence of work. Given that the use of the closed method is advisable in the case when the foundations for the equipment occupy a significant area of the spans of the building, in combination with the block-span method, this is the most rational method for industrial buildings with a developed underground part.

3. Results and Discussion

To determine the effectiveness of the developed block-span installation of the one-story industrial buildings roofing, the authors compare the technical and economic indicators of three installation methods: element-wise, large-block and developed one, using the methodology and data given in [1, 7, 19-22]. In the calculations for all options, the same conditions are accepted: the span width is 24 m, the span length is 96 m, the column height is 14 m, and the structures are installed by the MKG-25 crane.

The obtained data are given in table 1.

Table 1. Comparison of technical and economic indicators of the developed block-span installation method with element-wise [7] and large-block [10]

| Installation method | Indicator element          | Technical and economic indicators |   |   |
|---------------------|---------------------------|-----------------------------------|---|---|
|                     |                           | For 1 element                     |   |   |
|                     |                           | Labor intensity, man-hour         | 1.68 | 0.29 |
|                     |                           | Machine intensity, mash-hour      | 0.29 | 0.05 |
|                     | Secondary trusses         |                                    | 26.88 | 4.64 |
| Elementwise         | l = 12.0 m                |                                    | 14.10 | 3.32 |
|                     | Trussed rafters           |                                    | 225.6 | 53.12 |
|                     | l = 24.0 m                |                                    | 286.72 | 52.48 |
|                     | Roof stabs 3×6 m          |                                    | 539.2 | 110.24 |
|                     |                           | Σ                                  | 442.24 | 93.76 |
| Prefabricated       | Secondary trusses         |                                    | 1.16 | 0.20 |
| Large-block         | l = 12.0 m                |                                    | 18.56 | 3.2 |
|                     | Trussed rafters           |                                    | 179.2 | 45.76 |
|                     | l = 24.0 m                |                                    | 244.48 | 44.80 |
|                     | Roof stabs 3×6 m          |                                    | 442.24 | 93.76 |
|                     |                           | Σ                                  | 353.6 | 68.0 |
| Block-span          | Secondary trusses         |                                    | 0.98 | 0.15 |
|                     | l = 12.0 m                |                                    | 15.68 | 2.4 |
|                     | Trussed rafters           |                                    | 168.0 | 29.76 |
|                     | l = 24.0 m                |                                    | 185.6 | 35.84 |
|                     | Roof stabs 3×6 m          |                                    | 353.6 | 68.0 |

In addition, the developed block-span installation method takes precedence over element-wise one:

– quick completion of installation work on the entire span and presentation of the total scope of work for the implementation of subsequent construction processes: the construction of foundations and technological equipment, the installation of engineering communications and finishing work;

– it excludes control of the design position of the trussed rafters and secondary trusses at a height by combining the matchmarks on their ends on the supporting surfaces of the columns, since the entire block is verified at once on the extreme columns;
– it is not required to ensure the stability of each secondary truss by setting inventory spacers or by using a roof conductor strut;
– it excludes operations on the unsling and removal of temporary fastening of trussed rafters after welding of embedded parts of trussed rafters to embedded parts of columns.

When calculating the effectiveness of the developed installation method, element-wise one [7] was adopted as the base method. As calculations showed, with respect to the element-wise method, the use of a large-block method reduces the complexity of mounting by 18 %, machine intensity by 15 %. The block-span method developed by the authors allows to reduce labor intensity by 34.4 %, machine intensity by 27.5 %.

4. Conclusions
The developed block-span method of roofing structures assembling of one-story industrial buildings in comparison with the element-wise method allows:
1. To reduce the labor intensity of installation by 34.4 %.
2. To reduce machine intensity by 27.5 %. Even in comparison with the large-block installation method, block-span one reduces the labor input by 20 % and machine intensity by 27 %, that increases labor productivity.
3. To combination and sequence of work with the closed method of erecting industrial buildings. Given that, the use of the closed method is advisable in the case when the foundations for the equipment occupy a significant area of the spans of the building. In combination with the block-span method, it represents the most rational method for industrial buildings with a developed underground part.
4. To refuse work at a height and thereby increase the safety of work, while the quality control of construction and installation works is greatly simplified.

References
[1] Filimonova E A 2012 Methods of Searching for Optimal Parameters of Reinforced Concrete Structures Vestnik MGSU 10 pp 128–133
[2] Johnson R P 2004 Composite Structures of Steel and Concrete (United Kingdom (UK): Blackwell Publishing)
[3] Rutenberg A and Scarlat A 1990 Roof Bracing and Effective Length of Columns in One-story Industrial Buildings Journal of Structural Engineering 116(10) pp 2551–2566
[4] Hartkopf V and Loofness V 1999 Global Relevance of Total Building Performance Automation in Construction (Elsevier BV) 8(4) pp 377–393
[5] Yee Zaw CW, Thu Zar K and Thant K 2019 Roof Truss Design for Industrial Buildings Int. Journal of Advances in Scientific Research and Engineering 5(7) pp 103–112
[6] Bari N A A, Abdullah N A, Yusuff R, Ismail N and Jaapar A 2012 Environmental Awareness and Benefits of Industrialized Building Systems (IBS) Procedia – Social and Behavioral Sciences 50 pp 392–404
[7] Derysz J, Lewiński P M and Więch P P 2017 New Concept of Composite Steel-reinforced Concrete Floor Slab in the Light of Computational Model and Experimental Research. Procedia Engineering 193 pp 168–175
[8] Crapo H 1977 More on the Bracing of One-Story Buildings Environment and Planning B: Planning and Design 4(2) pp 153–156
[9] Palanci M 2019 Fuzzy Rule Based Seismic Risk Assessment of One-Story Precast Industrial Buildings. Earthquake Engineering and Engineering Vibration 18(3) pp 631–648
[10] Trutaev S Y 2014 Method for Stress-Strain-State Evaluation of Production Equipment and Buildings and Structures of Industrial Entities. Chemical and Petroleum Engineering 49(11-12) pp 816–819
[11] Kovalov V 2020 Investigation of the Influence of Determining Factors on the Efficiency Indicators of Organizational and Technological Decisions for the Reconstruction of Industrial Buildings Ways to Improve Construction Efficiency 0(43) pp 23–31
[12] Zileska Pancovska V, Petrusheva S and Petrovski A 2017 Predicting sustainability assessment at early facilities design phase. Facilities 35(7/8) pp 388–404
[13] Girmscheid G 2017 Lean Construction – Industrialisation of On-site Production Processes. Modernisation, Mechanisation and Industrialisation of Concrete Structures pp 301–345
[14] Asadollahfardi G, Asadi M and Karimi S 2015 Life-Cycle Assessment of Construction in a Developing Country Environmental Quality Management 24(4) pp 11–21
[15] Bhatt P 1997 Reinforced Concrete: Analysis and Design Engineering Structures 19(4) pp 336–337
[16] Kocherchenko V V, Kolchunov V I and Kocherchenko A V 1991 The method of installation of the building roof A S USSR № 1656100 A1 Bull № 2
[17] Krishan A L, Rimshin V I and Troshkina E A 2018 Strength of Short Concrete Filled Steel Tube columns of Annular Cross Section. IOP Conf. Series: Materials Science and Engineering 463 pp 022062
[18] Fard M M, Terouhid S A, Kibert C J and Hakim H 2015 Safety Concerns Related to Modular/Prefabricated Building Construction. Int. Journal of Injury Control and Safety Promotion 24(1) pp 10–23
[19] 1967 Development of Precast, Reinforced, and Prestressed Concrete Elements for Industrial Single-Story Buildings in Romania ACI Journal Proceedings 64(9)
[20] Mo Y 2002 Reinforced Concrete Structures New Directions in Civil Engineering
[21] Zou X-K and Li Qs 2005 Reliability-Based Seismic Performance Design Optimization of Reinforced Concrete Buildings Tall Buildings
[22] Salem O, Solomon J, Genaidy A and Minkarah I 2006 Lean Construction: From Theory to Implementation. Journal of Management in Engineering 22(4) pp 168–75