METHODS OF FORCED POSITIONING OF PREFABRICATED STRUCTURES DURING INSTALLATION OF BUILDING FRAMES

[a]HENNADII TONKACHEIEV, [b]LIUBOV LEPSKA, [c]SERHII SHARAPA, [d]MAKSYM KLYS, [e]VOLODYMYR RASKIVSKYI

[a-e]Kyiv National University of Construction and Architecture (KNUCA), 31, Povitroflotsky Ave., 03037, Kyiv, Ukraine
email: [a]tonkacheyev@gmail.com, [b]lyuba-lepskaya@ukr.net, [c]sergi.sharapa@gmail.com, [d]maxdbc@ukr.net, [e]rashkivskyi.vp@knuba.edu.ua

Abstract: The paper solves the current scientific and applied task to increase the efficiency of construction of prefabricated low-rise buildings by forming rational sets of equipment for forced landing, adjustment, and fixing structures. The hypothesis is confirmed that the substantiation and accounting of parameters of modules of limiters and clamps of assembly equipment at application of modern designs and butt connections of frameworks of low-rise buildings with ensuring forced placing and adjustment at formation of rational sets of assembly equipment will allow reducing labor intensity of erection. Taking into account the performed research, their analysis and processing, certain factors influencing the complexity and accuracy of the installation process are identified, as well as reasonable conditions for the use of modules of limiters and clamps of different types. The recommendations are aimed at designing the technology of erection of low-rise frame buildings for public and other purposes using butt joints, which are suitable for forced installation methods and for self-fixing methods. The problematic situations that have been considered concern the design parameters of joints and tolerances for the installation of structures. It is proved that during the installation of structures, there are errors in performing a number of operations.

Keywords: Fixing, Forced method of installation, Installation equipment, Low-rise frame building, Module, Restriction, Self-fixing, Set.

1 Introduction

At present, frame and frame-wall structural systems of buildings and structures have become widely used in public and residential construction (65…67% of the total construction volume). The trend of frame prefabricated monolithic construction shows that a large number of constructed objects are low-rise buildings, using modern butt joints, which opens the direction in the implementation of effective technologies using forced installation methods [18, 19]. Many factors influence the solution of the problem of creating and implementing the technology of forced installation of frame structures, which is currently the most promising in the field of construction of frame and wall buildings, as evidenced by the analysis of sources of leading construction companies in Germany, France, China, and others.

The trend of development of prefabricated monolithic frame construction is accompanied by improving the quality of buildings, which is associated with the use of modern technologies for the manufacture of prefabricated concrete and metal structures, with the current level of development of building materials [18, 19, 20, 29]. Achieving high quality of buildings depends on the accepted tolerances on the geometric dimensions of the frames and the ability to provide these tolerances in the process of their assembly, which, above all, affects the adoption of reasonable parameters of installation equipment [13, 14, 15, 16, 17].

The study of the actual accuracy and complexity of the installation of structures shows that the use of more advanced systems of technological equipment and the correct selection of its components in a set of parameters, increase accuracy, reduce complexity, and diminish operating time. Unreasonable use of expensive equipment with insufficient mechanization in technological processes leads to unjustified costs and reduced productivity, so the problem of forming sets of installation equipment while reducing costs for design, manufacture, operation and productivity is relevant.

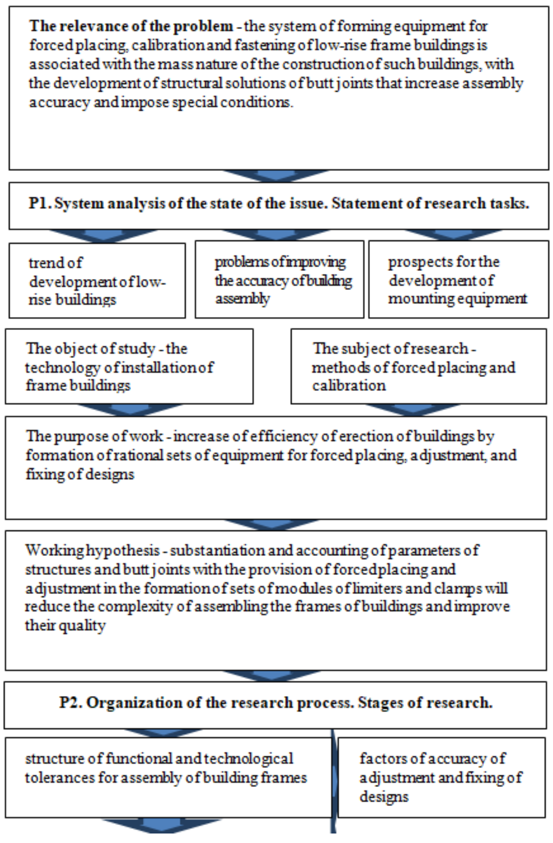
The solution to this problem is to create a system for forming sets of equipment for forced landing, calibration and fastening of low-rise frame buildings, while improving the design solutions of butt joints, which together will create conditions for the use of forced installation methods.

2 Materials and Methods

The purpose and objectives of the study were to increase the efficiency of erection of frame low-rise buildings by forming rational sets of equipment for forced placing, calibration and fastening of structures on the basis of scientific and practical methods of forming sets of prefabricated equipment. To achieve this goal, the following research objectives should be achieved:

- Perform an analysis of sources of information on the state of technology of erection of frame buildings and determine the scientific and technical level of development of technology for installation of structures of low-rise buildings;
- Investigate the design solutions of frames and butt joints of structures, functional and technological tolerances for the installation of frame structures that affect the accuracy of installation and reduce the complexity of the process;
- Investigate the influence of factors on the complexity and cost of installation of structures of frames of low-rise buildings using different modules of limiters and clamps;
- Develop a method of substantiation and selection of parameters of limiter modules and clamp modules in the formation of rational sets of installation equipment for the installation of frames of low-rise buildings;
- Provide recommendations for the design and use of mounting equipment kits for forced landing, calibration and fastening of structures of low-rise buildings.

A working hypothesis was formed, which is that substantiation and accounting of parameters of modules of limiters and clamps, as well as parameters of the process of assembly of structures with forced placing and calibration reduce the complexity of assembling building frames and improve their quality. This gave grounds to determine the main stages of the study in the form of methods (Figure 1).



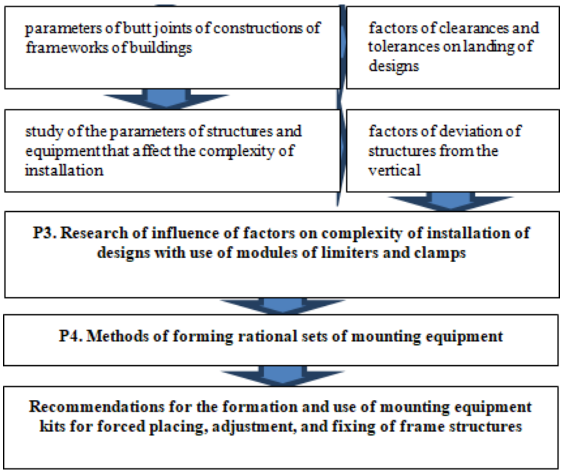


Figure 1 – Research algorithm

3 Results and Discussion

As a result of research of functional and technological tolerances on installation of designs of frameworks of low-rise buildings, contradictions between them are revealed that leads to decrease in level of assembly of designs that, in turn, is the cause of complexity of installation of designs with use of modern butt joints of bolt, pin and couplingtype. These contradictions, first of all, are connected with reduction of gaps of landing of system "hole-pin", secondly with existence of tolerances on turn of bearing surfaces which are characterized by systems "design-support" and "polyspast-design" [30].

To do this, studies were conducted on the possibility of rotation of the bearing surfaces of the columns and the rotation of the clamps for fixing columns with foundations, columns with columns, and crossbars with columns (Figure 2).

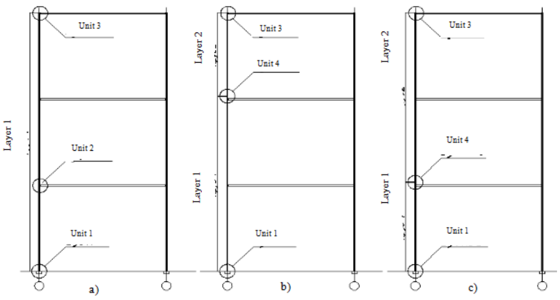


Figure 2 – Schemes of frames of frameworks with cutting into tiers and knots which were investigated:
a) with columns in one tier on two - four floors;
b) in two tiers with the first tier with columns on two floors;
c) in two tiers with the first tier with columns on one floor.

Studies of structural parameters of butt joints and parameters of the location of joints in the volume of the building allowed determining the list of significant factors influencing the complexity of the installation process [7, 8, 9, 10, 11, 12].

These include the gaps in the system of butt joints of the "pin-hole" type and the angles of deviation of the bearing surfaces and clamps in accordance with the existing system of functional tolerances for the structures of low-rise buildings (Figure 3).

These studies allowed assessing the situation with the movement of structures in terms of tolerances, which are fixed by the angle of rotation of the structures in space at certain ratios of the parameters of the structures and the limiting equipment.

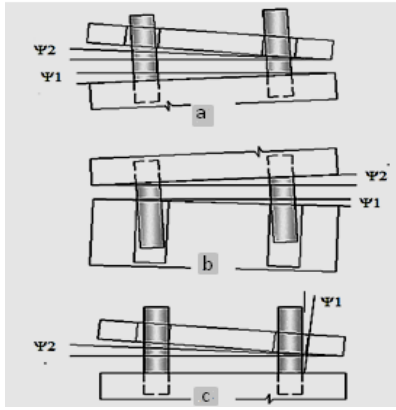


Figure 3 – Schemes of rotation of structures and supports in the nodes of frames of frameworks:
a) for units 2, 3 and 4 (see Figure 2);
b) for unit 4;
c) for unit 1.

As a result, for modern joints of structures, it is necessary to accept deviation of axes of prefabricated columns in the top section from a vertical no more than 8 mm for group clamps and no more than 12 mm for single clamps.

According to the results of the study of possible angles of rotation of the "structure-support" system, the values of reduced placing clearances are obtained, which for single clamps do not significantly affect the requirements for the angle of rotation of the "structure-support" system.

When limiting with increasing height of the limiting element of the mounted structure, which is typical for plug-type connections, it is necessary to increase the accuracy of their positioning in the vertical direction $\Psi = 0{,}5...1^{\circ} \pm 0{,}25^{\circ}$, which imposes very strict conditions on the accuracy of manufacturing and installation of limiters' modules.

To determine all the parameters of the system "pulley-structure", a model of the situation of installation of structures by cranes was developed, according to which groups of factors that affect the deviation of the system "pulley-structure" in the vertical plane at an angle ψ_2 were formed (Table 1).

Table 1: Factors that cause deviations of the system "polyspast-structure" in the vertical plane

Factors:			
S_i	groups:	S_{ij}	subgroups:
S_1	inaccuracies of the system of slinging structures:	$S_{1.1}$	errors in determining the position of the center of gravity of the structure
		$S_{1.2}$	errors in the location of the gripping elements
		$S_{1.3}$	errors in the length of the branches of the slings
		$S_{1.4}$	inaccuracy of placement on the structures of equipment and equipment that move with the structure
S_2	fluctuations of the system "polyspast – design":	$S_{2.1}$	action of inertial forces of the rope-block system
		$S_{2.2}$	air pressure on the assembly unit and slinging system
S_3	inaccuracy of positioning of structures on supports		

As a result of studying the parameters of structures and the system "polyspast-structure", it is determined that for structures of low-rise buildings, the total angle of rotation of supports and slinging structures does not exceed 2 degrees, which can cause jamming of structures when placing on latches "pin-hole" group type. For such butt joints, it is mandatory to use mounting equipment to return the induced structures to a vertical position with a decrease in angle to $\Psi = 0.5...1 \pm 0{,}25$.

By calculations, efforts were made to guide and orient structures when landing on supports (450… 1500 N) for the obtained values of the parameters of the system "polyspast-structure-support", which must be taken into account when creating and designing limiter modules and manipulator modules (Figure 4).

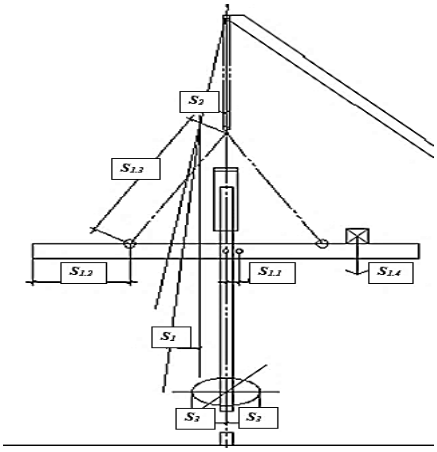


Figure 4 – Scheme of the system "polyspast – construction" with factors influencing the deviation of the system from the position in space

According to the results of the study of the existing time norms for installation processes, it is proved that in the case of fragmentation of components when changing structural and technological solutions of equipment, the norms do not change, which makes these norms unsuitable for analysis and evaluation of installation equipment [3, 4, 5, 6].

Based on the method of integer rationing, time norms for installation operations of the process of installation of columns, crossbars and floor slabs from the conditions of influence of deviations in the system "design-support" taking into account the factor of restrictions (gaps) in the system "pin-hole" butt joints implementation of coercive methods of landing, calibration and consolidation operations are determined.

With the help of network models, the processes of assembly of frame structures for the first cycles of the assembly flow, for typical and for the final cycles were built, which allowed combining complex models and conduct research by determining the technological parameters of the process (Figure 5).

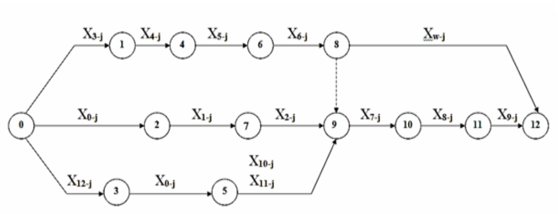


Figure 5 – Example of a network model of the variant (M3.1f1) for a typical cycle

A system of parameters and coefficients was proposed to evaluate the models of assembly processes (Table 2). According to the results of calculations, it is established that the use of limiter modules, which are included in the design of retaining modules together with locking modules installed on structures during their manufacture, is an effective way to improve the technology of low-rise frame buildings.

Table 2: System of parameters and coefficients of estimation of assembly process variants

Name of the indicator	Formula	Designation
the duration of the operational part of the critical path	$t_{cr} = \sum_{1}^{k} t_i^{cr}$	t_i^{cr} -duration of critical path operations
the duration of the non-operational part of the critical path	$t_0 = \sum_{1}^{q} t_j^0$	t_i^0 -duration of transitions
the average duration of the installation process	$t_m = \frac{t_{cr} + t_0}{n}$	n - the number of cycles included in one network model
duration of all operations of the network model	$t_s = \sum_{1}^{d} t_i$	
operating time of the main machines	$t_{va} = \sum_{1}^{v} t_i^{va}$,	t_i^{va} - duration of mechanized operations
coefficient of combination of operations	$K_{co} = t_s / t_{cr} \to 3$	
crane release factor	$K_{va} = t_{va} / t_{cr} \to 0$	
complexity of the installation process	$T_{\Sigma} = \sum_{1}^{d} t_i \cdot p_i + \sum_{1}^{q} t_j \cdot p_j$	p_i, p_j - number of performers for operations and downtime

Analyzing the obtained data, it is stated that for such indicators as the coefficient of combination of operations *kco*, as well as the coefficient of the operative part of the model *kom* changes in the values of the variants are almost insignificant. According to the coefficient of combination of operations *kco*, the oscillation of values is within 6%, and according to the coefficient of the operative part of the model *kom*, the oscillation of values is within 3%. According to the release factor of the crane*kva*, when installing columns, the oscillation of values is within 8% and decreases towards the models using modules of limiters and clamps, and when installing crossbars oscillation of values is within 20% and also decreases towards models using modules of limiters and clamps, which is explained by the greater distance between the supports for the crossbars.

The determining factors for characterizing the efficiency of the models are the average duration and complexity of the assembly cycle in the flow. To determine the average values, the following minimum number of installation cycles in the flow was adopted: when installing columns, the minimum number for the complex method of installation – 4 pcs, and for crossbars – 2 pcs.

The use of limiter modules and clamp modules in the installation of columns in models with autonomous movement and in models with movement together with modules holders in comparison with the basic models reduces the average cycle time by 7… 21% and labor intensity by 6… 20%, which confirmed the feasibility of modules of limiters and clamps.

The use of limiter modules and clamp modules when installing columns in models with movement together with modules holders in comparison with models with autonomous movement reduces the average cycle time and complexity by 5…17%, which also indicates the feasibility of forming equipment for forced placing, calibration, and fixation structures in one layout.
One of the main groups of errors is the displacement of anchors, pins, holes and couplings relative to the design axes, which leads to both inaccuracy of their location and rotation relative to the vertical. Therefore, the angle of rotation in the system "structure-support" and the angle of rotation in the system "structure-polyspasts" were substantiated and accepted as the determining parameter for the implementation of forced placing of structures on supports [29, 30]. Both of these angles reduce the gap in the "pin-hole" system, which can cause jamming of structures during placing on the supports, which, in turn, will complicate the installation process or make it physically impossible.

For installation of frameworks of low-rise buildings, the effort for guidance and orientation of structures when landing on supports is 450…500 N, and the conditional displacement of the center of gravity of the system (pulley structure) is within 100…200 mm, so, to return the structures to the horizontal position, it is necessary to create a moment of forces 45…100 Nanometers. For this case, one should choose the method of returning the structure to a horizontal position by balancing (counterload) in the upper level of the system. The weight of the counterweight is not too large to complicate the operating conditions for cranes.

To implement this method, the device "lifting traverse" of design was proposed by PhD in Technical Sciences, Tonkacheev [24, 25, 26, 27, 28]. In addition, this is the only solution of all considered, which allows, together with the reduction of the angle of rotation of the system "polyspast-structure", to quench the inertial oscillations of the system and keep the system in a given position from the wind (Figure 6).

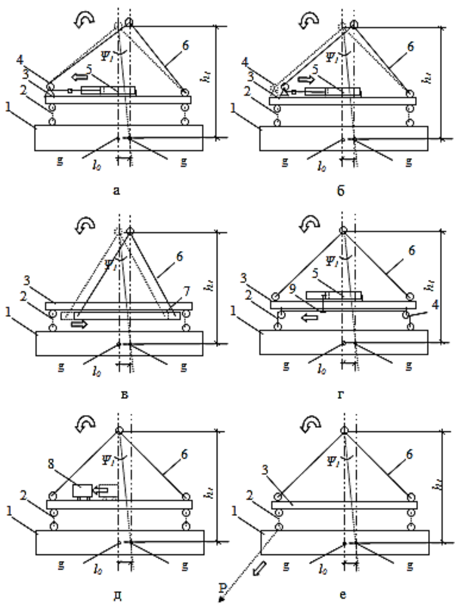


Figure 6 – Solutions for the arrangement of modules of holders and manipulators on the methods of bringing structures to a given position [1, 2]:
a - changing the length of the branches of the upper level slings;
b - changing the geometry of the upper level of the system by shifting the suspensions on the traverse;
c - displacement of the lower traverse relative to the upper without changing the geometry of the upper level;
d - balancing of a suspension bracket of a design in the lower level with adjustment of length of suspension brackets;
e - balancing (counterload) in the upper level of the system;
f - haul delay in the lower level of the system.

When installing columns, the problems with the deviation of the system "polyspast-structure" from the vertical is less than when installing crossbars and plates, so the traverse should be used only when installing crossbars by self-fixing, where the accuracy of positioning the structure $\Psi = 0{,}5...1^{\circ} \pm 0{,}25^{\circ}$.

The following solution is proposed in Figure 7.

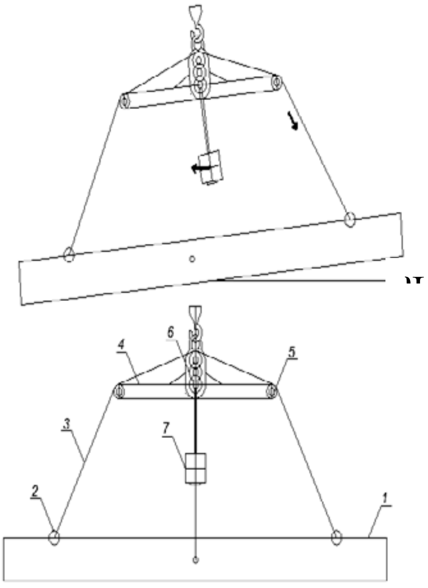


Figure 7 – Lifting traverse with construction balancer, by Tonkacheev [24].
1 - mounted structure; 2 - delight in the design; 3 - a branch of a sling; 4 - traverse; 5 - blocks; 6 - reducer; 7 - counterload.

To increase the accuracy of guidance of structures on supports (pins, bolts, holes, dowels), limiter modules should be used. The limiter module with a flexible infinite tape which is developed with participation of the author [10] (Figure 8) is offered for application.

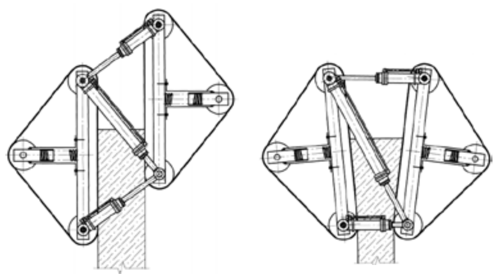


Figure 8 – Limiter module with flexible endless tape

The design of the module is universal and allows changing the sizes of an entrance contour of restriction under various sizes of the mounted designs, and under various diameters of deviation of designs at guidance by the crane in a zone of their placing on support.

As modules of clamps at installation of columns on anchor bolts, non-inventory disposable clamp, which allows reducing errors of placing of columns on bolts is offered. The clamp appeared to be cheaper than inventory and not difficult to install. With modern devices for drilling concrete and anchoring pins, the process is greatly simplified and the execution time is not problematic.

In modern technologies, non-inventory disposable clamps are often found. Compared to inventory portable modules, disposable clamps are simpler in design, not much more expensive, so in many cases more effective than reusable clamps. The basis of the method of self-fixing of prefabricated structures are non-inventory modules, clamps, fixed on the structures during their manufacture, which slightly increases the cost of structures.

Creation of modules of limiters and clamps of mobile type for prefabricated monolithic construction opens a new scientific direction in improvement of construction of buildings and structure to which the further researches will be devoted.

4 Conclusion

According to the research results, based on the dependences obtained in the previous sections, the process of forming rational sets of mounting equipment for forced mounting methods is divided into two algorithms: algorithm No.1 justification and selection of parameters of limiter modules and clamp modules; algorithm No. 2 formation of equipment sets for forced placing, calibration, and fastening of structures.

On the basis of the received data according to algorithm No.1, the final decision concerning a variant of modules of limiters and clamps for the further formation of sets of assembly equipment for forced landing, adjustment and fixing of constructions of frameworks of buildings is made.

For the formation of rational sets of equipment based on the method of prioritization developed an original algorithm No. 2 is designed, which allows identifying the most effective options depending on the parameters of frames, structures, butt joints, taking into account regulatory functional and technological tolerances. The basis for the assembly of options are mounting diagrams with a certain sequence of mounting frames and sets of mounting equipment.

Summarizing all the research results obtained in the work, recommendations for the design of installation technology and mounting equipment for forced placing, adjustment, and fixing of frame structures, which are tools for designers and manufacturers, are proposed.

Literature:

1. Afanasyev, A.A. (2000). *Technology of construction of prefabricated buildings*. ASV, Moscow.
2. Badin, G.M. & Sychev, S.A. (2013). *Modern technologies of construction and reconstruction of buildings*. BHV, St. Petersburg.
3. Beletsky, B.F. (2004). *Technology and mechanization of construction production* (3rd ed.). Phoenix, Rostov.
4. Chernenko, V.K. (2002). *Technology of construction production*. Vischa Shkola, Kyiv.
5. Chernenko, V.K. (2010). *Technology of installation of building structures*. Horobetz, Kyiv.
6. Erapov, V.Yu. (2006). Choice of constructive decisions of buildings. *Construction equipment and technologies, 5*, 58-65.
7. European level of comfort. (2011). *Construction and reconstruction*. Available at: https://stroy-ua.net/journal.html.
8. Flat, V.O. (2014). *Architecture of buildings and structures. Book 2. Dwelling houses: textbook*. PE “Medobory-2006”, Kamyanets-Podilsky.
9. Frank-Michael, A. (2001). *Improving the technology of construction of modular prefabricated low-rise buildings (on the example of the company BEECH, Germany).* PhD Thesis. Saint-Petersburg.
10. Goncharenko, D.F., Karpenko, Y.Y., & Meyersdorf, K. I. (2007). Accuracy as an indicator of static homogeneity and stability of the technological process of construction of high-rise frame-monolithic builders. *Journal “Building of Ukraine”*, 7, 35-40.
11. Granik, Yu.G. (2004). Design and construction of high-rise buildings. *New technologies in construction*, 1(7), 18-24.
12. Grebennik, R.A. (2009). *Installation of steel and reinforced concrete building structures.* Academy, Saratov.
13. Gurov, E.P. (2010). *Prefabricated housing. Development strategy*. StroyPROFil, St. Petersburg.
14. Individual reinforced concrete structures. (2013). *Frame constructions and other elements of construction of buildings*. Catalog. Available at: http://www.oberbeton.com.ua/ru/production.
15. Ischenko, L.V. (2007). Ensuring quality control in the construction of frame-monolithic buildings. *New technologies in construction,* 1, 47-51.
16. Joints and connections between building components. (2020). *Build ability Series*. Available at: https://www.bca.gov.sg/Publications/ /others/bsh_ch2.pdf.
17. Karpenko, Yu.V. (2008). *Technological maintenance of accuracy of geometrical parameters of designs of multistory frame-monolithic buildings.* PhD Thesis: 05.23.08. KhGTUSA, Kharkiv.
18. Livinsky, O.M., Dorofeev, V.S., & Ushatsky, S.A. (2012). *Technology of construction production*. LESYA, Kyiv.
19. Loveikin, V.S., Chovnyuk, Yu.V., Dikteruk, M.G., & Pastushenko, S.I. (2004). *Modeling of dynamics of mechanisms of load-lifting cars*. RVV MSAU, Kiev-Nikolaev.
20. Precast Concrete in Buildings. (2007). *The Concrete Center, 20 years*. Available at: http://www.concretecentre.com/online_services/publication_library/publication_details.aspx?PublicationId=650.
21. Precast Concrete Applications & General Overview. (2020). *Elematic group*. Available at: http://ru.scribd.com/doc/74358675/Precast-Concrete-Applications-General-Overview.
22. Privin, V.I. (2000). *Development of complex technologies of construction of multistory frame buildings*. PhD Thesis: 05.23.08. TsNIIOMTP.
23. Telichenko, V.I., Terentyev, O.M., & Lapidus, A.A. (2005). *Technology of construction processes*. Higher school, Moscow.
24. Tonkacheev, G.N. (2012).*Functional-modular system of formation of sets of construction equipment*. Prodigal MI.
25. Tonkacheev, G.M. & Lepskaya, L.A. (2011). Improving the accuracy of assembly of structures by reducing errors in performing operations of orientation and installation. *Urban Planning and Spatial Planning: Scientific tech. collection. KNUBA,* 41, 439-444.
26. Tonkachaev, G.M. & Lepska, L. A. (2012). Formation and selection of modules of technological equipment for planting and fixing prefabricated building structures. *Technology, organization, mechanization and geodetic support of construction: collection. Science. Bulletin of DonNACEA,* 6(98), 33-40.
27. Tonkacheev, G.M., Lepska, L.A., & Sharapa, S.P. (2014). System of substantiation of technological parameters of assembly equipment for limitation and fixing of mounted structures. *Urban planning and territorial planning: Scientific tech. collection, KNUBA,* 52, 418-426.
28. Tonkacheev, G.N. (2003). Fundamentals of the formation and selection of sets of assembly equipment in construction. *Mistobuduvannya and teritorialne planuvannya, KNUBA, 14*, 185-189.
29. Stolbova, S.Yu. (2003). *Perfection of the method of calculation of technological tolerances and substantiation of accuracy of installation of building designs.* Author's brief of dissertation of candidate of Tech. Sciences: 05. 23. 08, SibADI, Omsk.
30. Structural Connections Precast Concrete Buildings (2004). *Tecnopre.* Available at: http://www.tecnopre.com.br/f otos/downloads/GGJ3yi1316989697Structural%20Connections%20Precast%20Concrete%20Buildings%20-%20Parte%2004% 2004.pdf.
31. Volodin, V.P. & Korytov, Yu.A. (2008). *Assembly equipment for temporary fixing of prefabricated elements of erected and dismantled buildings*. JSC TSNIIOMTP, Moscow.

Primary Paper Section: J

Secondary Paper Section: JM, JN