UDC 69.057

DESIGN CALCULATIONS AND STUDY OF THE ASSEMBLY AND TECHNOLOGICAL INDICATORS OF COATING'S CONSOLIDATED STRUCTURAL BLOCKS

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DOI: 10.32347/2410-2547.2023.111.284-295

The article considers and implements the calculation model of the system using the design and calculation complex LIRA. The features of load perception and their rational distribution between structural elements are analyzed. The stress-strain state is calculated, taking into account the subsequent installation of the structure. The approach to determining the labor-intensiveness and duration of consolidation processes during the installation of structural blocks of the covering, which is caused by atypical structural and technological solutions, is considered.

Modern approaches to the process of consolidation of structural blocks of coatings are analyzed. The use of load-lifting assembly modules is proposed to reduce the specific share of the use of heavy crane equipment at the construction site. The method of installation of a structural coating with the use of heavy crane equipment and load-lifting installation modules is compared.

Keywords: calculation of structures, stressed-deformed state, consolidation of structural blocks of the coating, technological process, lifting and assembly module, metal structure, labor intensity.

1. Introduction

In recent years, the problem of designing and building structures for temporary accommodation of people, organization of logistics hubs, functioning of command centers, etc. has become urgent. The process of erecting such structures is very limited in time, and resources are limited. Most often, buildings of light metal structures with spans of 18...36 m are erected for this purpose. However, taking into account the wide range of existing means of mechanization, as well as the creation of new ones, the task arises of calculating the stress-strain state of structures and developing new erection technologies, determining their indicators and taking them into account during design. At the same time, approaches to the technology of installation/dismantling of buildings are reviewed.

To the questions of research by technological of installation/dismantling of buildings are described in the works [1, 8, 9, 12, 13]. A review of complex technological systems considered as part of the process of erecting building structures and the indicators of these systems are given in the works [3-10].

2. Research analysis

In accordance with the design task, the constructions are calculated.

This article calculates the stress-strain state of structures in the LIRA software complex, taking into account subsequent assembly (fig. 1-3). The frame is calculated in accordance with:

- DBN V.2.6-198:2014 "Steel structures. Design standards" [14],
- DBN V.1.2-2:2006 "Loads and impacts. Design norms" [15],

- DBN V. 1.2-2-2006 System for ensuring the reliability and safety of construction objects. Loads and influences. Design norms [16],
- DSTU B V.1.2-3:2006 - Deflections and displacements of design requirements [17].

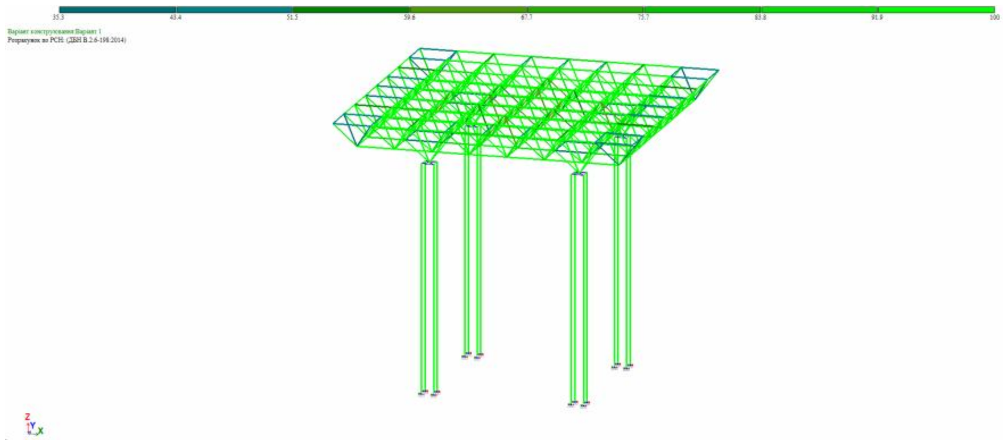

Fig 1. Verification according to the I limit state

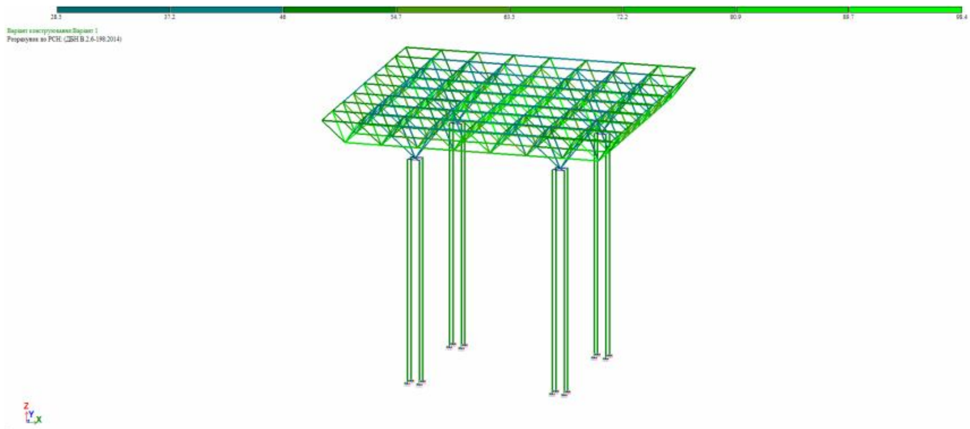

Fig. 2. Verification according to the II limit state

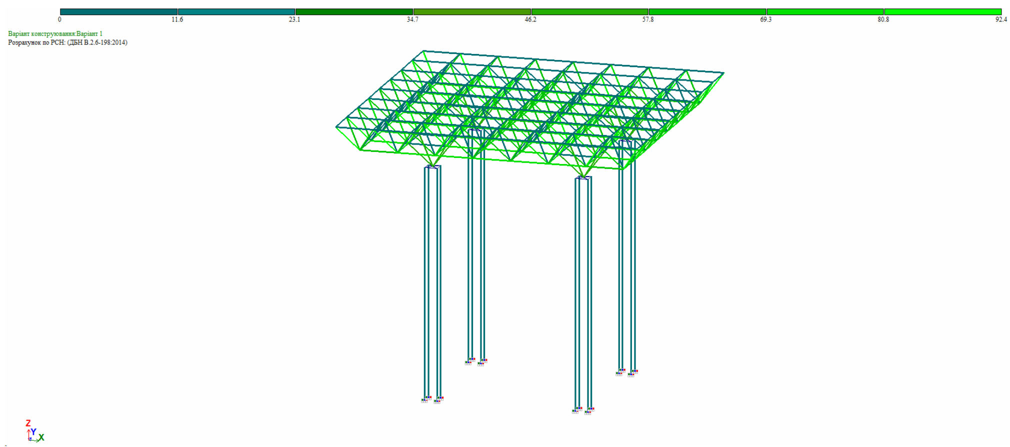

Fig. 3. Verification local stability

The main requirements for technologies are the speed of assembly while maintaining a high level of reliability and accuracy. Technologies with forced methods of lifting and installing structures and structural blocks of the covering are considered the most relevant for this [2] (Fig. 4).

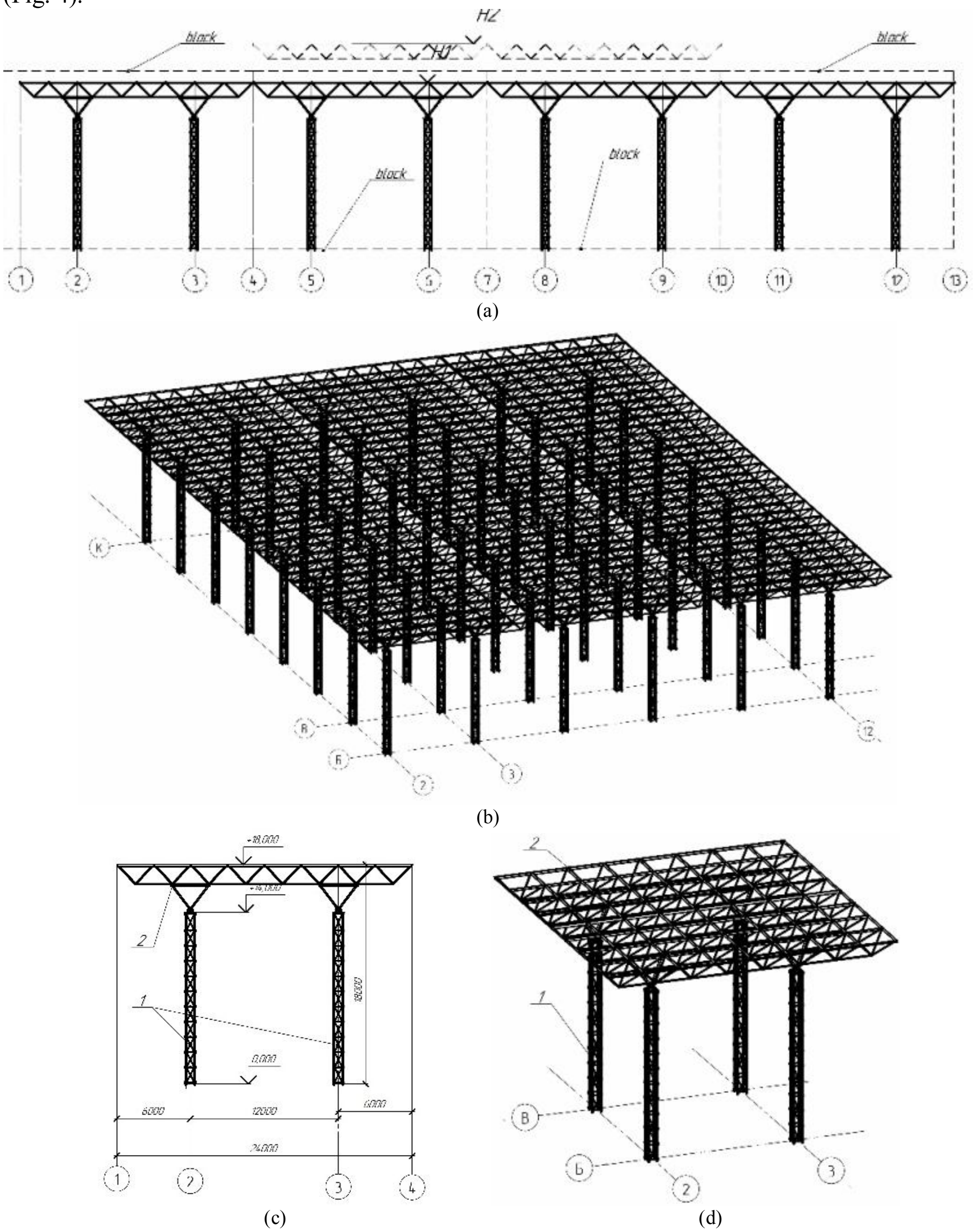

Fig. 4. General view of structural coating: (a) – frontal view of structural coating ; (b) – isometric view; (c) – frontal view of block 24x15 m; (d) – isometric view of block 24x15 m: 1 – the column; 2 – coating

In order to shorten the installation time of multi-span structures, as a rule, consolidation of the building elements directly on the site by specialized assembly teams is used. The process of consolidation of structural blocks of the coating can take place on special platforms, on mobile stands or on assembly lines (Fig. 5). For the structural block coating technology of installation using cranes, the zones for consolidation of the structural coating blocks are placed close to the installation locations. These areas must be within the range of the cranes. To lift the structural covering without using of heavy cranes, reinforcements are usually performed on the ground in the plan of the axes of the supporting structures.

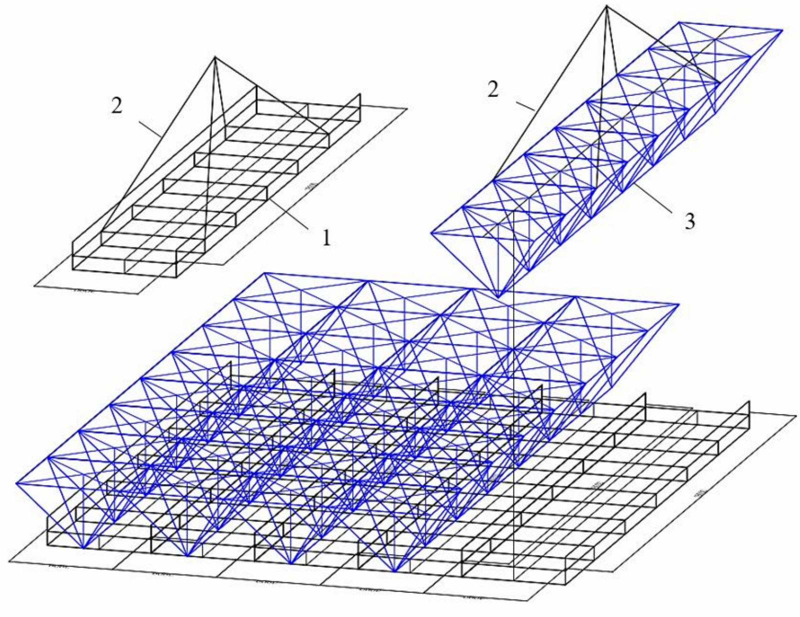

Fig. 5. Scheme of consolidation of the structural blocks of the coating 15 x 24 m:
1 – assembly stand block; 2 – sling; 3 – the starting mark of the structural blocks of the coating

For the basic version, the columns are first mounted (columns with a height of 12 m are used for the analysis), so it is not possible to carry out consolidation in the area of the columns. The stands are placed next to each other in the working area of the crane. According to the accepted installation scheme, a crane with increased load capacity is needed. The LTM 1090 crane (Fig. 6) was conditionally accepted for the analysis. The weight of the covering block with corrugated board and part of the equipment for the example is 12 tons, the reach of the crane boom is 16 m, the lifting height of the crane hook is 24 m. With such parameters, the crane's carrying capacity is 12,5 tons [1].

The comparison of options involves the inclusion in consideration of the processes of installation of columns (build-up), installation of stands, consolidation of blocks, installation (lifting) of blocks and installation and movement of a crane or assembly lifting and gathering modules.

Structural blocks of the covering includes the process of installing assembly stands and consolidation. The labor intensity and duration of these processes depend on the size of the outgoing stamps. Since the production of structural elements at the factory is a robotic process, it is advisable to make the initial stamps as large as possible in size. Depending on the restrictions of highways [12], the following dimensions of the starting mark are adopted for the structures: length – 24 m, width – 3,0 m, height – 2,12 m. The number of starting marks per block is 5 pieces. In addition, four more starting marks of the supporting pyramids are added. For the assembly of all brands in the block, rods are supplied in bulk in the amount of 32 pcs. The starting mark of the collection stand has a length of 21 m, a width of 3,0 m and a height of 0,5 m. The number of starting marks of the stands is 5 pcs.

A mobile crane with a lower load capacity is required for the installation of stands and consolidation of structural blocks of the covering. The maximum load weight of this process is 2,0 tons, so a truck crane with a load capacity of up to 16 tons is sufficient.

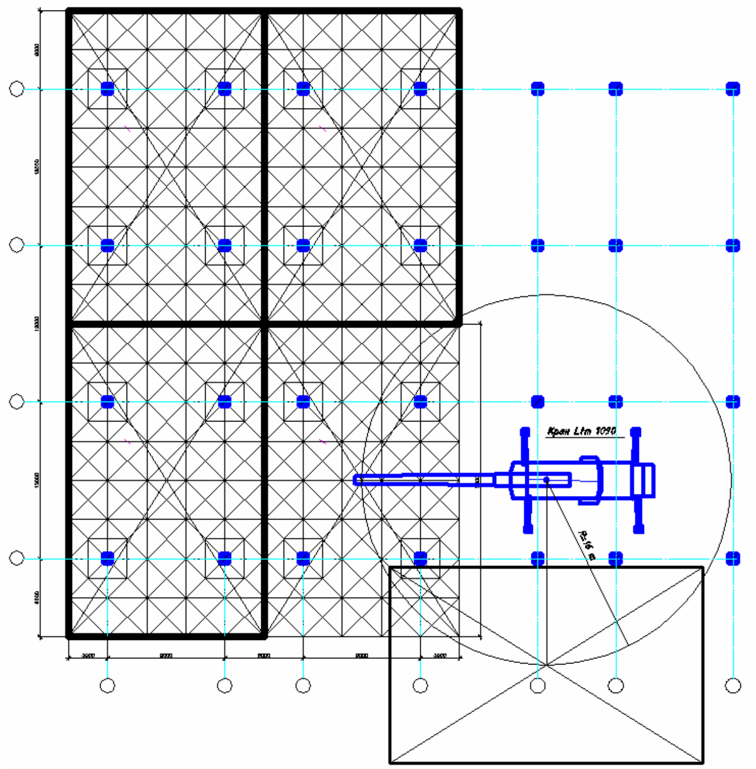

Fig. 6. Scheme of consolidation and installation of the structural blocks
of the covering 15×24 m according to the basic version

The labor intensity and duration of consolidation of structural blocks of the covering are also found using the method of integer normalization (tables 1, 2).

Table 1

The matrix for calculating the parameters of the installation process of assembly stands

Actions, W_i	Number of actions by level of responsibility, r_j					T_h, min	Number of performers N_p, human	Labor costs Θ, human-min
	1	2	3	4	5			
$W_{4.1}$		**5**				10	4	40
$W_{4.2}$			**5**			15	4	60
$W_{4.3}$			**5**			15	4	60
$W_{4.4}$	**5**					5	4	20
$W_{4.5}$		**5**				10	3	30
$W_{4.6}$				**5**		16	3	48
$W_{4.7}$		**5**				10	3	30
$W_{4.8}$					**1**	5	2	10
Results:						76		298

The structure of the installation process of folding stands is similar to the structure of the installation process of columns, but does not require additional installation equipment for temporary fixing and calibration:

$W_{4.1}$ – transition of performers to a new work area;

$W_{4.2}$ – workplace preparation;
$W_{4.3}$ – feeding the crane hook and slinging the structure;
$W_{4.4}$ – lifting and feeding the structure to the installation area;
$W_{4.5}$ – guidance of the structure when entering the landing area and landing on sleepers;
$W_{4.6}$ – verification and final fixation of the initial stamps;
$W_{4.7}$ – removal of sling grabs;
$W_{4.8}$ – acceptance quality control.

Table 2

Matrix for calculating the parameters of the structural blocks of the coating consolidation process

Actions, *Wi*	Number of actions by degree of responsibility, r_j					T_h, min	Number of performers N_p, people	Labor costs Θ, man-min
	1	2	3	4	5			
$W_{5.1}$	**9**					9	4	36
$W_{5.2}$			**9**			27	4	108
$W_{5.3}$			**9**	**1**		31	5	155
$W_{5.4}$		**9**			**1**	23	5	115
$W_{5.5}$			**9**			27	3	81
$W_{5.6}$			**9**			27	3	81
$W_{5.7}$					**9**	45	3	135
$W_{5.8}$			**10**			30	4	120
$W_{5.9}$			**64**			192	3	570
$W_{5.10}$			**10**			30	3	30
$W_{5.11}$					**5**	25	2	50
Results:						457		1481

Actions $W_{4.1}$, $W_{4.2}$, $W_{4.3}$ can be combined. *T* manpower of the assembly stand installation process is: Θ_h = 0,01667×298 = 4,968 man-hours and the duration of the process with a combination of actions is T_h = 0,01667 x 76 x 1,12 = 1,42 hours.

The structure of the consolidation process consists of the following actions:
$W_{5.1}$ – transition of performers to a new work area;
$W_{5.2}$ – workplace preparation;
$W_{5.3}$ – feeding the crane hook and slinging the structure;
$W_{5.4}$ – lifting and feeding the structure to the installation area;
$W_{5.5}$ – guidance of the structure when entering the landing zone and landing;
$W_{5.6}$ – temporary fixation of the sending stamp;
$W_{5.7}$ – verification and final fixation of the initial stamps;
$W_{5.8}$ – removal of sling grabs;
$W_{5.9}$ – installation and fixing of individual rods of the structure;
$W_{5.10}$ – raising the structural blocks of the coating to the height of the supporting structure (4.0 m);
$W_{5.11}$ – acceptance quality control.

Actions $W_{5.1}$, $W_{5.2}$, $W_{5.3}$ can be combined. The complexity of the process of enlarging Θ_h=0,01667×1481 = 24,688 man-hours.

The main process is the installation of the structural blocks of the covering unit. To carry out this process, it is necessary to separate the process of preparing workplaces, since it is related to height. To organize the placement of workplaces, and there are four of them, mechanized scaffolding of the pantograph type on self moving machines (carriage) should be used. The structure of the process is as follows:
$W_{6.1}$ – entrance of mechanized scaffolding to parking lots;

$W_{6.2}$ – bringing the scaffolding to working condition;
$W_{6.3}$ – lowering and raising work platforms.

According to the method of integer rationing [13], the labor intensity of the process of preparing four workplaces is: Θ_h=0,01667×200 = 3,334 man-hour and the duration of the process with a combination of actions is T_h = 0,01667×120×1,12 = 2,24 hours.

The structure of the process of lifting and installing the structural blocks of the coating consists of the following actions:

$W_{7.1}$ – supply of the crane hook and slinging of the structural blocks of the covering 24x15 m;
$W_{7.2}$ – preparation of column anchors;
$W_{7.3}$ – installation of spacers and supporting nuts;
$W_{7.4}$ – preparation of the structure for installation;
$W_{7.5}$ – lifting and feeding the structure to the installation area;
$W_{7.6}$ – guidance of the structure when entering the landing area;
$W_{7.7}$ – orientation and installation of the structural blocks of the covering on the anchor bolts;
$W_{7.8}$ – installation of nuts and rough fixing of the structural blocks of the covering;
$W_{7.9}$ – calibration and final fixation of the structural blocks of the covering unit;
$W_{7.10}$ – removing the sling grabs and returning the crane hook;
$W_{7.11}$ – acceptance control of the installation quality of the structural blocks of the covering.

To determine the labor-intensiveness and duration of the installation of the structural blocks of the covering, the scale of the duration of actions has been changed, since the process is carried out over long distances (Table 3).

Table 3

Matrix for calculating the parameters of the structural blocks of the covering installation process

Action s, *Wi*	Number of actions by level of responsibility, r_j								Duration T_h, min	Number of performers N_p, people	Labor costs Θ, man-min
	1	2	3	4	5	6	7	8			
$W_{7.1}$						**4**			24	4	96
$W_{7.2}$						**4**			24	8	192
$W_{7.3}$				**16**					64	4	256
$W_{7.4}$					**4**				20	4	80
$W_{7.5}$						**2**			12	3	36
$W_{7.6}$							**2**		14	3	52
$W_{7.7}$								**4**	32	5	160
$W_{7.8}$				**16**					64	4	256
$W_{7.9}$					**16**				80	4	320
$W_{7.10}$		**2**			**4**				24	4	96
$W_{7.11}$								**2**	16	2	32
Results:									350		1576

Actions $W_{7.1}$, $W_{7.2}$, $W_{7.3}$ and $W_{7.4}$ can be combined. The complexity of the process of enlarging Θ_h=0,01667×1576 = 26,272 man-hours.

According to the methodology [1], a schedule of the consolidation and installation of the structural blocks of the covering with preliminary installation of the columns according to the corresponding calculations was made (Table 4).

Table 4

Technological calculations of the process of setting up a frame with structural blocks of the covering (see Fig. 6)

Code process	Product volume		The rate of labor costs, man-hour	Time consumption rate, hours	Labor intensity of the process, man-hours	Duration of the process, hours
	Unit	Quantity				
TR1	1 parking lot	40	1,834	0,88	73,360	35,20
TR2	1 column	32	1,050	0,62	33,600	19,84
TR3	1 column	32	2,817	1,34	90,144	42,88
TR4	1 stand	8	4,968	1,42	39,744	11,36
TR5	1 block	8	24,688	8,53	197,506	68,26
TR6	4 works places	8	3,334	2,24	26,672	17,92
TR7	1 block	8	26,272	7,48	210,176	59,84
TR8	%	5			33,672	12,77

The general structure of the processes is as follows:
TR1 – installation of a crane on parking lots;
TR2 – unloading and dismantling of columns;
TR3 – installation of columns;
TR4 – installation of folding stands;
TR5 – consolidation of SBP blocks;
TR6 – preparation and maintenance of workplaces;
TR7 – installation of SBP blocks;
TR8 – other not taken into account processes (5%).

According to the results of calculations, with the technology of arranging eight pieces of structural blocks of the covering in separate cycles, the basic version (with a crane) has a lower labor intensity of the process by 1197,454 – 707,114 = 490,34 man-hours, which is 41% as a percentage. The duration of the process according to the basic option is shorter by 282,67-268,07 = 14,6 hours, which is 6% faster than according to the new option. The main factor is the number of lifting cycles. For 8 structural blocks of the covering, according to the basic version, the number of lifting cycles does not change (8 cycles), and according to the new version, it is possible to lift the covering in 8, 4, 2, and in one cycle. According to the results of the study of the influence of the dimensions of the assembly blocks, the following dependence was obtained (Table 5, Figs. 6, 7).

Fig. 7. Graphs of the dependence of the labor intensity of the frame arrangement with the basic and new version on the degree of consolidation of the structural coating

The total costs for the basic version are:
Work intensity – 707,114 human-hours;
Duration – 268,07 hours.

Table 5

Technological calculations of the frame installation process depending on the level of consolidation of the structural blocks of the covering

Code	Unit measure ment	8 blocks		4 blocks		2 blocks		1 block	
		Θ_h, man-hours	T_h, hours	Θ_h, man-hours	T_h, hours	Θ_h, man-hours	T_h, hours	Θ_h, man-hours	T_h, hours
TR1	1 block	36,272	17.36	36,272	17.36	36,272	17.36	36,272	17.36
TR2	1 block	14,936	7.2	14,936	7.2	14,936	7.2	14,936	7.2
TR3	1 block	256	64	170,667	42.67	113,778	28.45	75,852	18.96
TR4	1 block	120,024	38,24	112,124	37.84	108,120	37,44	100,120	37.04
TR5	1 block	475.20	78,41	471.20	39,20	467.20	19.6	463.20	9.8
TR6	1 block	256	64	248	60	240	56	232	52
TR7	%	57,022	13.46	52.66	10,21	49,015	8.30	46,119	7,12
Together:		1197,454	282.67	1105,859	214.48	1029,321	174.35	968,449	149.48

According to the schedule, the labor intensity of the processes under the new option remains high according to basic option. Reduction in labor intensity by 5-10%, but the labor intensity of the basic version is 41-25% less.

This indicates that there is a need to improve the lifting assembly module through the use of robotics and the transition to automation of processes, which is real and possible for the proposed design.

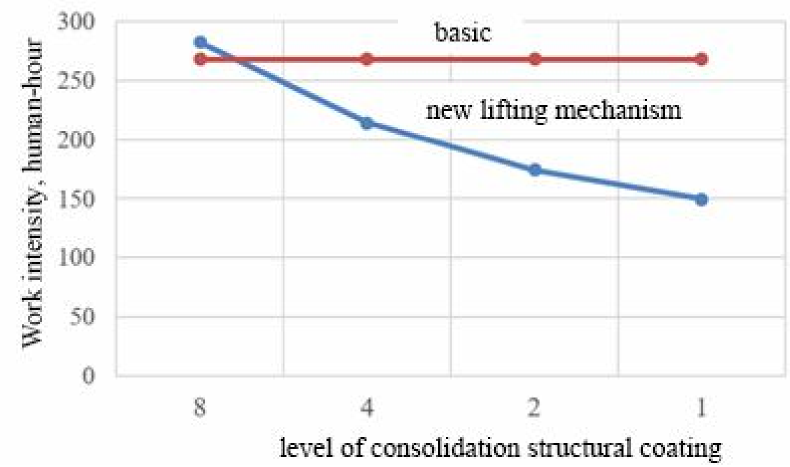

Fig. 8. Graphs of the dependence of the duration of the installation of the frame with the basic and new version on the degree of consolidation of the structural covering

According to the schedule, the duration of processes under the new option is significantly reduced in relation to the basic option. The reduction in duration occurs by 33-50%, and in relation to the basic version, the reduction in the completion time begins when moving to the consolidation stage of 4 blocks of 2 structural covering - by 20-40%.

3. Conclusions

1. According to the results of the conducted research, there was a need to develop a schematic diagram and a constructive solution of the lifting and collecting module. The lifting-collecting module is designed for lifting the structural blocks of the covering with the simultaneous building up of columns.

2. A study of the labor-intensiveness and duration of the installation processes of the structural blocks of the covering was carried out according to the options of crane and crane-less installation methods. To ensure the principle of comparability of options, the processes of column installation (building up), stand installation, block consolidation, block installation (lifting) and installation and movement of a crane or assembly lifting and collecting modules are included in the consideration. All calculations are based on the method of integer normalization. Based on the results of the study, all the components of the labor intensity and duration of the processes were determined, on the basis of which the schedules for the consolidation and installation of the structural blocks of the covering were built.

3. According to the schedule, the labor intensity of the processes under the new option remains high. in relation to the meringue version. Reduction in labor intensity by 5-10%, but the labor intensity of the basic version is still 41-25% less. This indicates that there is a need to improve the new mounting machanism through the use of robotics and the transition to automation of processes, which is real and possible for the proposed construct.

4. The advantages of the new option become very significant when it comes to the rapid construction of temporary structures.

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Стаття надійшла 21.11.2023

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РОЗРАХУНОК КОНСТРУКЦІЇ ТА ДОСЛІДЖЕННЯ ТЕХНОЛОГІЧНИХ ПОКАЗНИКІВ УКРУПНЕНОГО СКЛАДАННЯ СТРУКТУРНИХ БЛОКІВ ПОКРИТТЯ

У статті розроблено та реалізовано із застосуванням проектно-обчислювального комплексу LIRA розрахункова модель системи. Розміри і кількість СЕ моделі дозволяють коректно досліджувати НДС конструкції. Розглянуто підхід до визначення трудомісткості та тривалості процесів укрупнення при монтажі структурних блоків покриття, що зумовлено нетиповими конструкційними та технологічними рішеннями. Актуальністю даної роботи є потреба у якісному аналізі методів розрахунку параметрів технологічних процесів при синтезі рішень механізації монтажних процесів.

Проаналізовано сучасні підходи щодо процесу укрупнення структурних блоків покриттів. Запропоновано використання вантажопідйомних монтажних модулів для зменшення питомої частки використання важкої кранової техніки на будівельному об'єкті. Порівняно спосіб монтажу структурного покриття із застосуванням важкої кранової техніки та вантажопідйомних монтажних модулів.

Для забезпечення принципу порівняння варіантів до розгляду включені процеси монтажу колон, монтажу стендів, укрупнення блоків, монтажу блоків та встановлення і переміщення крану або монтажних підйомно-збиральних модулів. Всі розрахунки виконувалися у табличній формі відповідно до формули методики цілочислового нормування. За результатами дослідження визначені всі складові трудомісткості та тривалості процесів, на підставі яких побудовано графіки виконання процесів укрупнення і монтажу блоків СБП.

Ключові слова: розрахунок конструкцій, напружено-деформований стан, укрупнення структурних блоків покриття, технологічний процес, підйомно-збиральний модуль, металоконструкція, трудомісткість.

UDC 6 9.057

Тонкачеєв Г.М., Іванченко Г.М., Рашківський В.П., Козак А.А., Нестеренко І.С. **Проектні розрахунки та дослідження складально-технологічних показників укрупнених конструкційних блоків покриття /** Опір матеріалів і теорія споруд: наук.-тех. збірн. – К.: КНУБА, 2023. – Вип. 111. – С. 284-295.
Табл. 5. Іл. 8. Бібліогр. 17 назв.

UDC 69.057

Tonkacheev G.M., Ivanchenko G.M., Rashkivskyi V.P., Kozak A.A., Nesterenko I.S. **Design calculations and study of the assembly and technological indicators of coating's consolidated structural blocks** // Strength of Materials and Theory of Structures: Scientific-&-Technical collected articles. – Kyiv: KNUBA, 2023. – Issue 111. – P. 284-295.
Tabl. 5. Fig. 8. Ref. 17.

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