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Organizational and Process Design Solutions for Sports Facilities

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ABSTRACT
Currently, special attention is given to the construction of sports venues. Every new facility is not just walls and grounds:most of them are well-designed buildings, stadiums, skiing runs, cycle tracks, impoundments, ice rinks, roller skiing trails, beach sports recreation centers, providing up-to-the-minute equipment for mass sports activities. The latest and most efficient engineering solutions must be applied in construction of such complex systems. Modern sports facilities are built from complex projects; engineers try to design the most convenient conditions for sports activities. They also strive to make facility meet its operational purpose, while being architecturally beautiful and unique. Sometimes organizational and process design solutions are very labor intensive, because technical standard framework does not provide necessary data, in particular the standard time of roofing process, which requires expert-based set of norms. The paper analyzes the experience of Russia and several foreign countries on trial organizational and process design of roof at sports facilities. As a result of the research, a flow chart was drawn up for makinga plan of the construction of a sports facility, taking into account the decomposition of works according to the degree of their typing in terms of standards of technical rate setting. These developments work for improvement of organizational and process design. In addition, they shape a comprehensive approach to estimation of non-standard labor intensive works, which require extra study through actual technical regulation at construction sites.

Introduction

Construction of long-span buildings and structures is a complex process that requires a careful approach of the developer and contractor as well as a sound technology of work. Construction of large-scale objects has its own direction in design, though there is no definition in technical standard base of what a «long-span structure» or a «long-span facility» are (*table 1*).

***Table 1**. Classification criterion of a long-span building / structure*

No.	*Source of standard documentation*	*Classification criterion of a long-span building / structure*		
		Span, m	*Metric area*	*Cantilever, m*
1.	Resolution of the Moscow Government No. 567-PP dated June 25, 2006 "On measures to ensure the reliability of civil buildings with long-span structures"	>18	-	-
2.	"Manual on scientific and technical support and monitoring of buildings and structures under construction, including long-span, high-rise and unique ones" MRDS 02-08, section "Terms and definitions"	>36	-	-
3.	MDS 20-2.2008 "Temporary recommendations on ensuring the safety of long-span structures from progressive collapse in case of emergency impacts"	>36	-	-
4.	Town-Planning Code of the Russian Federation "Article 48.1. Highly dangerous, technically complex and unique facilities"	**>100 (term «unique» is used)**	-	-
5.	Code of Practice dated 25.10.2017 No. 304.1325800.2017 "SP 304.1325800.2017 Structures of long-span buildings and facilities. Rules of operation"	**>18 (civil)** >30 (industrial)	**>50 people**	**>9**

2. Literature Review

A number of regulatory documents [2,3,4,5] and scientific sources [1,6,7,8,9,10,11] were analyzed and studied, in order to write this paper and fully convey the most relevant and precise information, scrutinize various data and terns.

3. Method

Public, industrial and special buildings are usually designed with long spans. The necessity for such structures arises when intermediate supports obstruct the planned work process. The bearing elements of such objects can be made of the following basic materials - in-situ reinforced concrete, prefab reinforced concrete, piece elements. Such long-span buildings are usually made single-span. Facilities of industrial and special type generally are rectangle, while public ones can polygonal-, round- or oval-shaped.

Existing methods for construction of long-span sports facilities on the example of football stadiums.

Every country discusses the matter of human life expectancy and healthy life style. The President of Russia gave interesting figures: to date, 54 million Russians take sports on a regular basis, what is almost 40% of the country's population. Moreover, there has been set a goal to increase this figure to 55% by 2024 [11]. Accordingly, there is a great need for the active construction of sports facilities, including those for major international competitions.

Many sports venues, such as football stadiums, have a large area and exclude, due to the architectural solution, the presence of bearing pillars inside the building, i.e. those buildings are long-span. Sports facilities range by their functional purposes (*table 2*).The paper considers those stadiums in more details, the roofing of which was conducted in various methods depending on structural system of cover (*table 3*). Having analyzed a number of such sports venues, it becomes clear that distinctive feature of the design and implementation of organizational and process solutions lies primarily in erection of long-span architecturally vivid roofing and facades (*table 4*).

Table 2. *Classification of sports facilities by functional purpose*

No.	*Facility*	*Description*	*Athletic discipline*
1.	Sports and recreation facility (premises)	Equipped with special technical means and intended for fitness and health, sports services	All team sports, gymnastics, wrestling, powerlifting
2.	Sports arena	Sports ground with grandstands. Outdoors >1500 people, indoors >500 people.	All team sports, gymnastics
3.	Gym hall	A sports, indoor facility >18 m long, >9 m wide and >5 m high (if the size is smaller, it is deemed a "facility for sports purposes"), there is equipment for different sports or universal. It may be situated in a sports building. .	All team sports, gymnastics, wrestling, powerlifting, track-and-field athletics
4.	Indoor arena	A covered separate or built-in structure that meets the size requirements of the educational and training process and the rules of competitions in sports using large-sized plane structures (fields, sports grounds, etc.) as the main ones. Seats for spectators are possible.	Football, track-and-field athletics, equestrian sport, swimming
5.	Sports complex	A group of similar and different types of volumetric and plane structures for training and competitions, located in the same territory and run by one management. Facilities can be interlocked, located under the same roof or free-standing.	All team sports, gymnastics, wrestling, powerlifting, track-and-field athletics
6.	Stadium	It is a complex with sports arena.	Football, cycling, running, track-and-field athletics
7.	Universal Sports and Entertainment (Demonstration) Hall (Sports Palace)	Arena for 1000 and more people. The sizes of the main ground and the auditorium are suitable for different sports. Versatility is achieved through transformation.	Team sports, hockey, figure skating
8.	Swimming pool	An open-air or indoor facility with a main swimming-bath of at least the size set by the competition rules. It is possible to combine conditions for several sports in one bath It is possible to arrange seats for spectators.	Competitive swimming, water polo, springboard diving, synchronized swimming
9.	Shooting range	It is a complex, consisting of open or semi-enclosed facilities.	Various kinds of shooting
10.	Skiing center	A complex of facilities, including changing rooms, ski storage and other service rooms and trails for training and skiing. A skiing run may include a ski stadium - a start and finish area >400m in length and width with a judge's room, grandstands for spectators	Alpine skiing, snowboarding, biathlon, orienteering, freestyle, ski jumping

Table 3. *Classification of the main structural systems of stadium roofs*

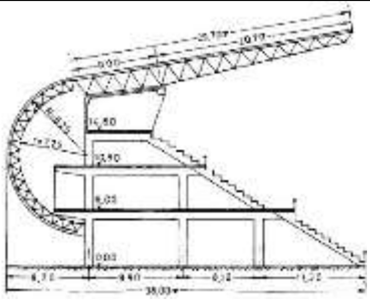
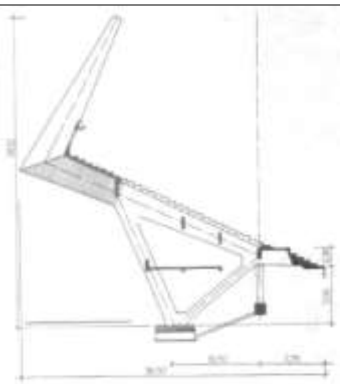
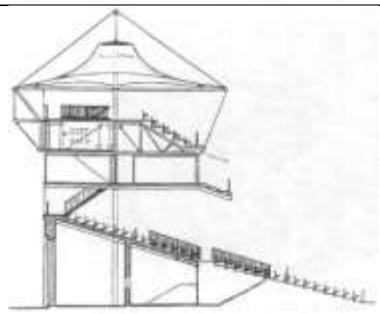
No.	*Type of roof structure*	*Options of roofing structural system*	*Description*	*Drawing*
1.	Canopy above the stadium stands (cantilever-beam system)	Stadium in Hong Kong	Canopy roof of Hong Kong stadium is made with wave-like folded plates rom synthetic materials, which are placed on the metal-elements structure	
2.	In-situ reinforced concrete cantilever beams	Stadium in Düsseldorf, Germany	One end of the beams rests on the girder of in-situ triangular reinforced concrete frames, and they are suspended by cables to the upper part of the girder at two other points. The section of the beam is T-shaped, between the beams the covering is a suspended reinforced concrete cylindrical shell.	
3.	Steel cables	Cricket ground in London, UK	Canopy tent structure covers the stands of the renovated cricket venue in London. To steel tubular masts attached cables and suspended a dome made of transparent synthetic material - polycarbonate.	

Table 4. *Examples of sports facilities*

No.	*Name*	*Purpose*	*Capacity, people*	*Unique elements (non-standard structural / architectural / organizational and process solutions, previously not implemented in civil engineering)*	*Photos from Internet sources*
1.	The Volgograd Arena, Volgograd, Russia	Football stadium	45,568	Roofing	
2.	Otkritie Arena, Moscow, Russia	Football stadium	45,360	Roofing, facade	
3.	Bilbao Arena, Bilbao in the province of Biscay, Spain	Basketball arena	8,793	Roofing, facade	

The Volgograd Arena's roof resembles a bicycle wheel made from strong steel cables. The facility is located in a historical place; its compactness is achieved due to the canonical shape of the facade tapering downwards. The pattern on its self-supporting structures of the facade is inspired by local traditional weaving from canes and a firework at the celebration of the Victory in the Great Patriotic War. Primarily, the main pre-construction activities were performed, including the dismantling and disposal of building structures of the former Central stadium and the previously existing utility systems. Then the work of the principal construction period – making a foundation pit and a foundation slab – was performed. Further, the stadium's supporting structures were erected, on-site utility systems were laid, cast-in-situ structures and stands of the stadium were constructed with a total volume of more than 120 thousand m^3 of concrete. In 2017, the installation of horizontal structures of the stadium roof was completed, including a unique cable-stayed system with a membrane covering. [7.8]

When erecting **Otkritie Arena**, one of the trickiest moments was to assemble the stadium's roofing system. The workers mounted 8700 tons of metal at a height of 29 to 36 meters with the help of a large number of complex lifting mechanisms. The roof structure involves two longitudinal trusses (an architectural truss is a building part installed for the rigidity and strength of the structure. It is usually used when building complex spans) installed along the football pitch, and two transverse trusses forming a cross-linked system over the stadium. The roof trusses framed along the upper and lower chords with steel sheets 4 mm thick, were assembled on the ground on special trolleys in just near the facility to cover. The trolleys had conductors and devices to ensure the necessary accuracy of putting together the roof elements. The design of the trolleys allowed them to move along horizontal and inclined rail tracks with trusses fixed on them. To lift the trolleys to the design level, two inclined mounting beams were installed. The trolleys with the next roofing block were moved via two block and tackle systems. After reaching the design mark, the trolleys rested against a special buffer; the roofing block was lowered onto steel cages and pushed into the final position by rolling-on method with the help of two light blocks and tackles. In the final position it was first raised via jacks to release the rollers, and then lowered back to the final position. One of the advantages of this method is that there is no need to use a crane of large-tonnage capacity. The facade of the stadium is made of cement-mineral panels. Their advantage consists in their ability to take a wide range of shapes. The construction project was developed by the architect bureau AECOM. Initially, they wanted to make the facade of blocks and bricks, but later decided to use newer technologies of "dry construction". The walls of the facade are resistant to moisture, which is an important factor, since only one of the four stands is heated. The scaly facade was designed by Dexter Moren Associates, the British bureau. The design of the outer walls is such that they are effectively protected from atmospheric agents. [9]

A noteworthy green facade solution was made for **Bilbao Arena** in Spain. The structure of the arena is inspired by a leaf of a tree. The facade plating is made of leaf-like steel plates that can be removed to allow more light and air to enter the building. This design helps cut expenses on electricity; the halls are well-aerated; an air conditioner is not required. The largest arena is located at the top of the building, while the smaller sports grounds are at the lower part of the complex. The upper arena is naturally illuminated due to glass partition-walls of utility spaces which let the outdoor light in. There is a rainwater collection tank, which is not common for this type of structure. Water is collected in a special container and transferred to the disposal of the city municipality. This water is further used for washing the streets of Bilbao. The sports arena occupying 30,808 m^2 requires a huge amount of electricity, but due to its energy efficient design the actual consumption is reduced many times over. The total area of the building is 80,000 m^2, and the problem of air conditioning of such a space is also solved in environmentally friendly way: by "perforation" of the green facade. [10]

Proceeding from architectural and design solutions for similar projects, some options of organizational and process design also contain uncommon solutions. For instance, in the Russian Federation besides the concept design and detailed design documentation, which is developed by engineering companies, certain regulations impose upon a contractor a duty to develop organizational and process solutions formalized in the form of production documents (Work execution design, Flowsheets of operational sequence, Production procedures) [2]. Such organizational and process solutions are prescribed even at the design stage in the Construction Management Plan. However, this solution requires a deeper investigation into options for performing works at the stage of construction.

4. Results

A building or a structure should be erected in compliance with an activity schedule contained in the process control documentation. The procedure of compiling such a schedule, in particular for construction of unique long-span sports facilities, is shown in the flowchart below *(see Figure 1)*.

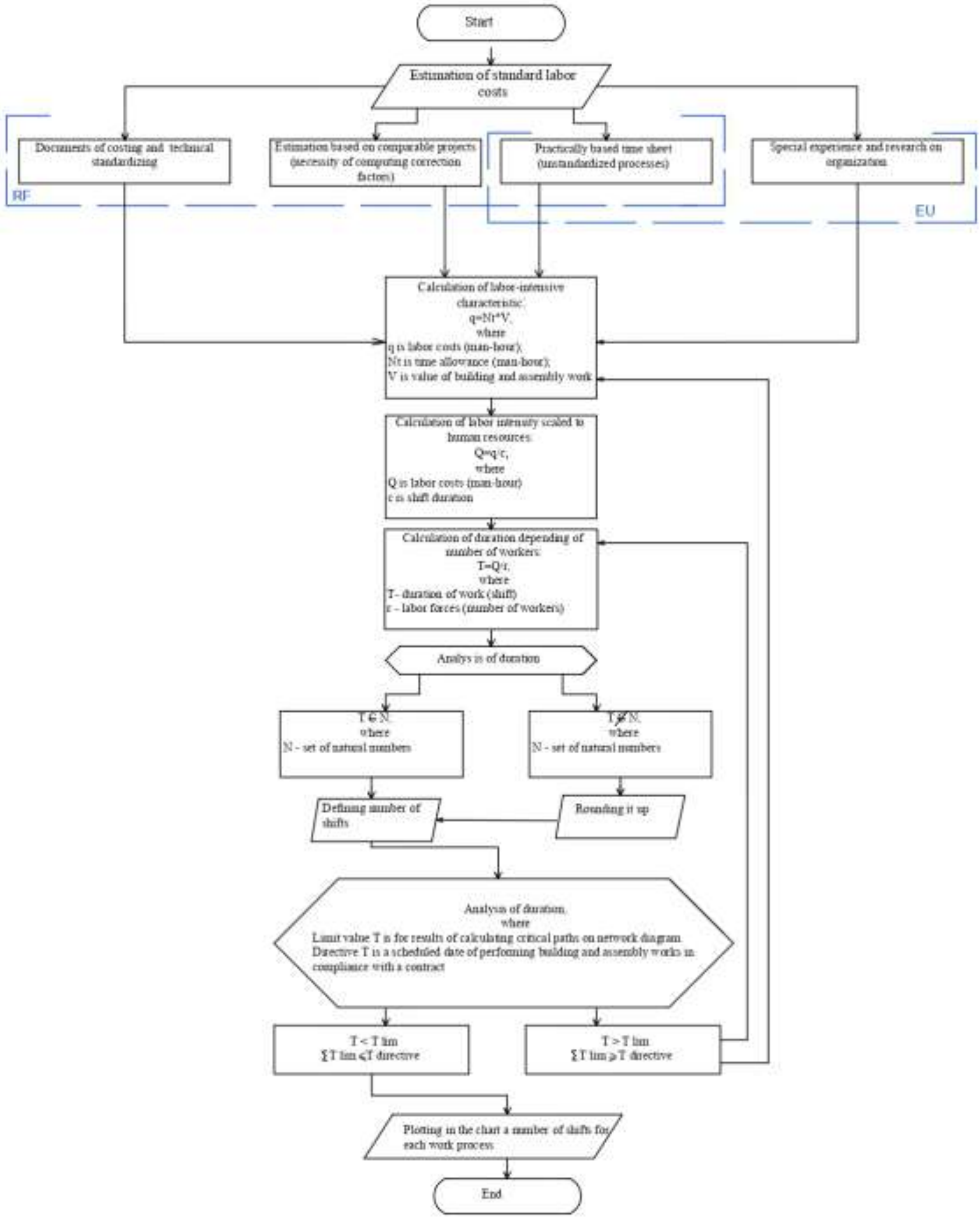


Figure 1. *Flowchart of the process of plotting a linear Gant chart for performing one particular type of work.*

As one can see from the chart above, the process of compiling an activity schedule is based on technical rationing. Time allowance is given in a number reference papers, yet there are no some of certain building and assembly works performed when erecting a unique structure with the use of unstandardized technologies. Within the framework of this study, the authors propose to resolve the complex of building and assembly works associated with construction of sports facilities into elementary processes, which are offered to systemize by splitting into certain groups on the grounds of standardization of process rating. After analyzing a number of projects, two types of work are given *(see Figure 2)*.

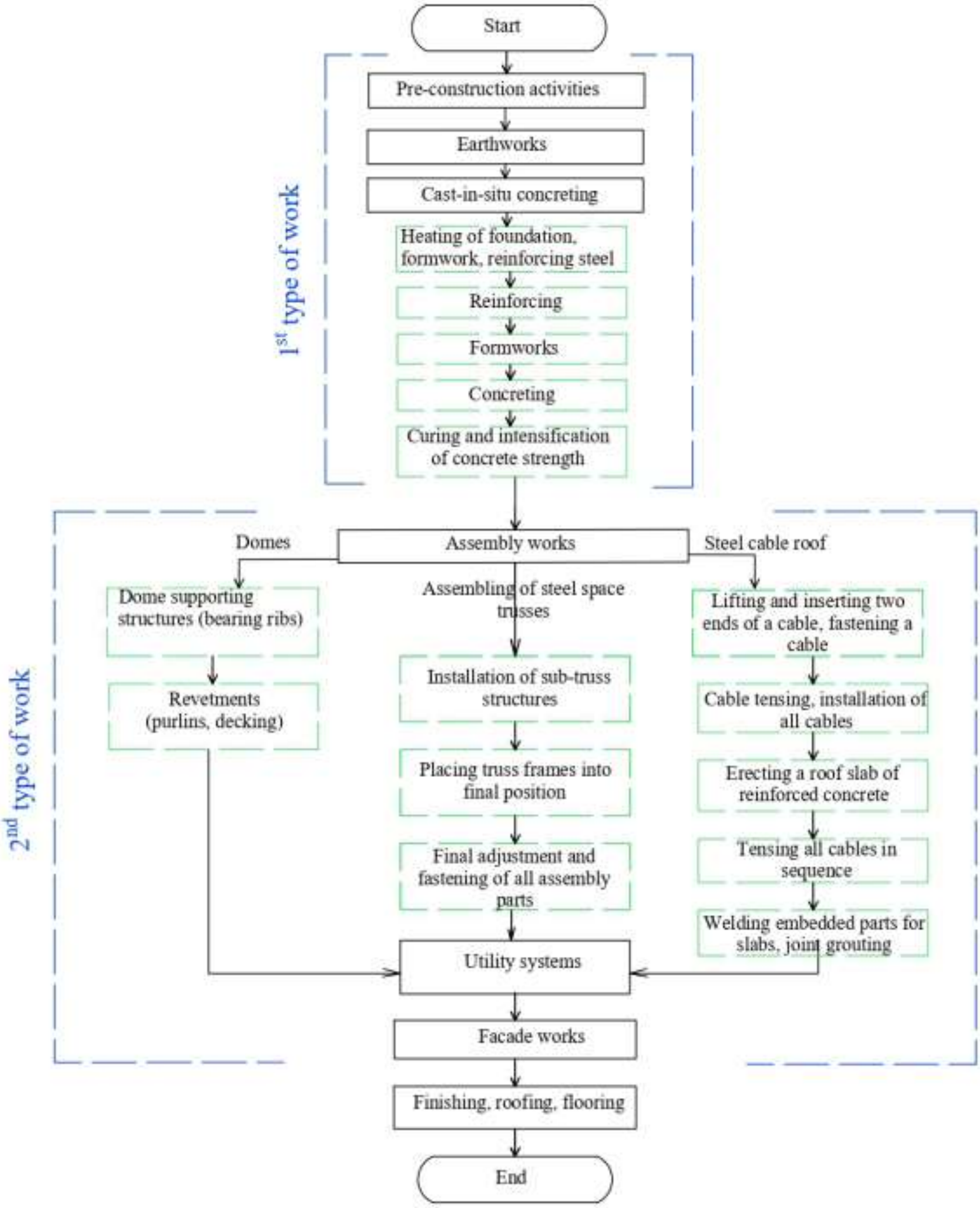


Figure 2. *Flowchart of the process of erecting a stadium*

In terms of organizational and process solution, the first type of work is similar to the one pertaining to projects meant for other purposes. The second type comprises works that require quite time-consuming process of determining time rates (practically-based time sheet on site). However, after resolving these groups of works into processes one can distinguish “standardized” ones, technical rate setting of which require no additional time. Exotic technology for erecting stadium’s roofing such as a method of circular lengthwise launching may serve as an example of trial design. Another one – suspended cantilever method, which is more common and time-tested, may be used as an example as well. *(see Table 5)*

Table 5*. Example for assembling space trusses*

№n/n	*Works*	*Processes*	*Mathematical formalization* $q_{i,j}^{I,II,III}$
I	1st category works on erecting sports facilities that do not require practice-based rate setting		
I_1	In-situ concreting [1.1]	Reinforcing	q_{11}^{I}
I_2		Formworks	q_{12}^{I}
I_3		Concreting	q_{13}^{I}
I_4		Curing and intensification of concrete strength	q_{14}^{I}
I_5		Maintenance	q_{15}^{I}
II	2nd category works on erecting sports facilities that require unstandardized mechanical means		
II_1	Suspended cantilever method [1.2]	Assembly of steelwork of external abutments	q_{11}^{II}
II_2		Preparation of basement for vertical support members	q_{12}^{II}
II_3		Pre-assembly activities, mounting, ground level assembly works	q_{13}^{II}
II_4		Подача монтажного блока на рабочей площадке временных опор Conveying sub-assemblage on temporary supports’ site	q_{14}^{II}
II_5		Pre-assembly of sub-assemblages	q_{15}^{II}
II_6		Dismantling steelwork and temporary supports	q_{16}^{II}
III	3rd category works on erecting sports facilities that require practice-based rate setting		
III_1	Method of circular lengthwise launching [1.3]	Installation of launching nose	q_{11}^{III}
III_2		Assembly of auxiliary mounting elements to perform launching	q_{12}^{III}
III_3		Installation of jack, winches and guide casings	q_{13}^{III}
III_4		Elementwise supply of launching to a bay with regular assembly	q_{14}^{III}

Mathematical formalization of the calculation of labor costs for building and assembly processes and works is presented in the formulas

$$Q^I = \sum_{i=1}^{n} Q_i^I = \sum_{i=1}^{n}\sum_{j=1}^{m} q_{ij} \quad [1.1],$$

where

Q^I *- total labor intensity of building and assembly works of the 1st category;*

Q_i^I *- labor intensity of the i-th work of the 1st category;*

$\sum_{j=1}^{m} q_{ij}$ *- sum of labor intensity of j processes of the i-th work of the 1st category;*

i- counting number of work in this category;

j - counting number of the work process in this category;

n– number of works in this category;

m- number of work processes in this category

$$Q^{II} = \sum_{k=1}^{n'} Q_k^{II} = \sum_{k=1}^{n'} \sum_{l=1}^{m'} q_{kl} \quad [1.2],$$

where

Q^{II} *- total labor intensity of building and assembly works of the 2nd category;*

Q_k^{II} *- labor intensity of the k-th work of the 2nd category;*

$\sum_{l=1}^{m'} q_{kl}$ *- sum of labor intensity of l processes of the k-th work of the 2nd category;*

k - counting number of work in this category;

l - counting number of the work process in this category;

n'– number of works in this category;

m'- number of work processes in this category

$$Q^{III} = \sum_{h=1}^{n''} Q_h^{III} = \sum_{h=1}^{n''} \sum_{r=1}^{m''} q_{hl} \quad [1.3],$$

where

Q^{III} *- total labor intensity of building and assembly works of the 3rd category;*

Q_h^{III} *- labor intensity of the h-th work of the 3rd category;*

$\sum_{r=1}^{m''} q_{hr}$ *- sum of labor intensity of r processes of the h-th work of the 3rd category;*

h - counting number of work in this category;

r - counting number of the work process in this category;

n''– number of works in this category;

m''- number of work processes in this category

5. Conclusion

The introduction of an algorithmic approach to elaboration and technical and economic assessment of organizational and process design solutions in the case of trial design of technology for assembling large-span structures for sports buildings and facilities allows improving and optimizing procedures of working out organizational and process documents through resolving building and assembly works into categories. This allows maximizing the use of experimental data on erection of such objects. Algorithmization of organizational and process design reveals the following tasks that require further study:

1. Standardization of organizational and process solutions for the construction of unique sports facilities in order to optimize organizational and process design in general and the possibility to timely develop various options for assembly technology (including uncommon non-standard technologies).

2. Application of the described prerequisites for creating an automated algorithm for the development of rational organizational and process solutions for the construction of unique large-span sports facilities (and corresponding software).

The proposed standardizing of works was used when working out an organizational and process model for the construction of several sports facilities. The example is trial designs of a technology for assembling the roofing of Otkritie Arena in Moscow (Russia). Depending on a type of structural properties of sports facilities' roofing, elaboration of various standard organizational and process models allows accelerating the development of organizational and process documentation, determination of key production parameters (total labor intensity, duration, cost) according to a way of implementation of a corresponding technology. Trial design also optimizes the range of tasks associated with technical regulation of building and assembly processes at site.

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