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ERECTING CONSTRUCTIONS OF COMPLEX CONFIGURATION WITH USING OF PNEUMATIC FORMWORK

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Abstract. Reinforced concrete thin-walled large-girder shells of complex configuration – remarkable and efficient structures that are used to create accent in the most important places of society. One of the main advantages of reinforced concrete thin-walled large-span shells is that the loss of stability of individual structural elements does not lead to immediate destruction. When building monolithic structures, it is easier to solve problems associated with joints and their sealing. The absence of seams in buildings prevents the formation of cracks, increasing the structural strength and durability in operation. This, in turn, favorably effects on the sound-, heat- and waterproofing of the structure. Efficiency of the erection of such buildings is ensured by: low cost of construction; high carrying capacity; safety in operation, even if the part of the structure is damaged; small own weight, which does not have a great influence on the geotechnical environment; the possibility of erection in hard-to-reach areas. Modern technologies allow erect buildings and structures quickly, of various configurations, regardless of the elements type. The main reason behind the massive construction of shells in Ukraine is the disproportion between the optimality of thin-walled structures and the disadvantages of their construction methods, which are based largely on the experience of the flat systems construction. A detailed analysis of the formwork systems made it possible to select the formwork for buildings and structures of complex configuration.

Keywords: reinforced concrete shells of complex configuration, pneumatic formwork, monolithic concrete, dome, wavy bundle.

ЗВЕДЕННЯ КОНСТРУКЦІЙ СКЛАДНОЇ КОНФІГУРАЦІЇ З ЗАСТОСУВАННЯМ ПНЕВМАТИЧНОЇ ОПАЛУБКИ

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Анотація. Залізобетонні тонкостінні великопрольотні оболонки складної конфігурації – визначні і ефективні споруди, які використовуються для створення акценту в найважливіших місцях суспільства. Їх використання забезпечується: низькою вартістю конструкції; високою несучою здатністю; безпекою в експлуатації, навіть при пошкодженні частини конструкції; малою власною вагою, що не робить великого впливу на геотехнічну обстановку; можливістю зведення на важкодоступних територіях. Основною причиною, що стримує масове будівництво оболонок на Україні є диспропорція між оптимальністю тонкостінних конструкцій і недоліками методів їх зведення, які базуються здебільшого на досвіді будівництва плоских систем. Детальний аналіз опалубних систем дозволив зробити вибір опалубки для будівель та споруд складної конфігурації.

Ключові слова: залізобетонні оболонки складної конфігурації, пневматична опалубка, монолітний бетон, купол, хвилястий звід.

ВОЗВЕДЕНИЕ КОНСТРУКЦИЙ СЛОЖНОЙ КОНФИГУРАЦИИ С ПРИМЕНЕНИЕМ ПНЕВМАТИЧЕСКОЙ ОПАЛУБКИ

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Аннотация. Железобетонные тонкостенные большепролетные оболочки сложной конфигурации – выдающиеся и эффективные сооружения, которые используются для создания акцента в важнейших местах общества. Их использование обеспечивается: низкой стоимостью конструкции; высокой несущей способностью; безопасностью в эксплуатации, даже при повреждении части конструкции; малым собственным весом, что не оказывает большого влияния на геотехническую обстановку; возможностью возведения на труднодоступных территориях. Основной причиной, сдерживающей массовое строительство оболочек на Украине, является диспропорция между оптимальностью тонкостенных конструкций и недостатками методов их возведения, которые базируются в основном на опыте строительства плоских систем. Детальный анализ опалубочных систем позволил сделать выбор опалубки для зданий и сооружений сложной конфигурации.

Ключевые слова: железобетонные оболочки сложной конфигурации, пневматическая опалубка, монолитный бетон, купол, волнистый свод.

Goal. The article provides information on the choice of formwork for buildings and structures of complex configuration. The correct choice depends on the material, construction, installation and dismantling of the formwork. **Methodology.** Based on the information and practical solutions studied, a classification of modern formwork systems was developed. **Results.** As practice shows, not all formwork systems can be effective in the erection of buildings of complex configuration. This is due to their installation, the difficulty to give the appropriate form, which leads to an increase in the duration and cost of work. Detailed study of formwork systems allowed to find the right formwork solutions for the erection of buildings with complex geometry. **Practical value.** For each form of formwork there is a certain area of usage.

Relevance. When building is erecting in modern conditions, concrete got widespread use both in Ukraine and abroad. Constructions of concrete are made in various shapes quite quickly, aesthetically and qualitatively. Formwork is used to perform complex structural elements of buildings and structures. Correctly selected formwork allows you to reduce the duration of work and the labor intensity and cost of an erecting building or complex construction configuration. Therefore, the relevance of the issue is reduced to the correct choice of formwork for the implementation of a complex configuration of the structure.

Therefore, the **purpose** is to choose the design of the formwork for the erection of buildings or structures of complex configuration.

The **task** is as follows: to analyze information sources and choose an alternative version of the formwork for the construction of buildings or structures of complex configuration.

Consider the usual types of formwork. Figure 1 shows the classification of modern formwork systems.

Depending on the purpose, the formwork can be temporary and permanent. Metal, wood, and synthetic materials are used as the material for the formwork.

Depending on the area of usage, the forms have different shapes and configurations (Fig. 2).

As can be seen from Figure 2, not all types of formwork can be used to erect buildings of complex configuration. This is primarily due to the design of the formwork and its area of usage.

Methodology. A review of the literature sources in which the technology of erecting concrete monolithic thin-walled coatings with the use of pneumatic formwork was researched. This issue is dealt with by well-known scientists, specialists in this field both in Ukraine and abroad: B.I.

Petrakov, V.P. Selivanov, A.S. Nikitin, V.V. Ermolov, A.S. Arzumanov, V.A. Chertov, D.V. Belov, A.M. Yugov, Mario Cappellini, Dario Zucchi, A.Michelagnoli, E.Bubner and others.

Each of the listed authors was engaged in the development of formwork for the construction of buildings of complex configuration.

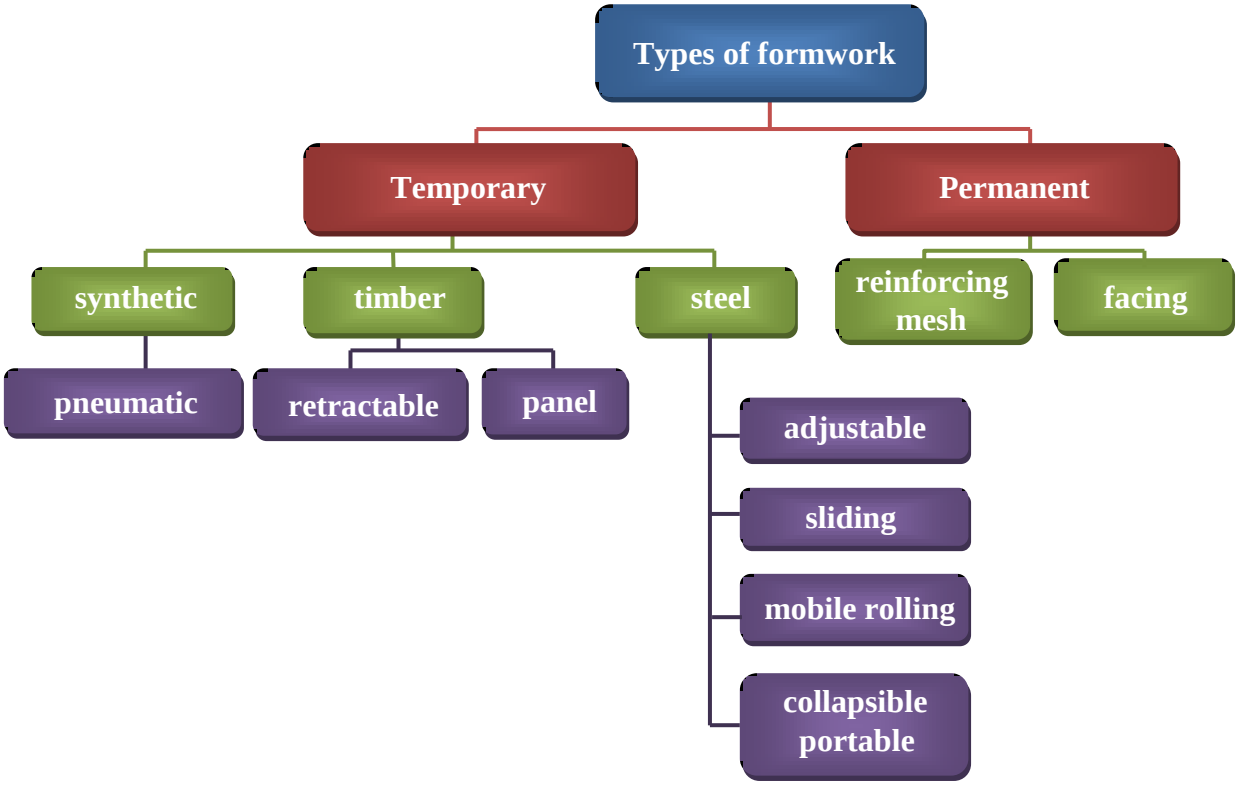


Fig. 1. Types of modern formwork

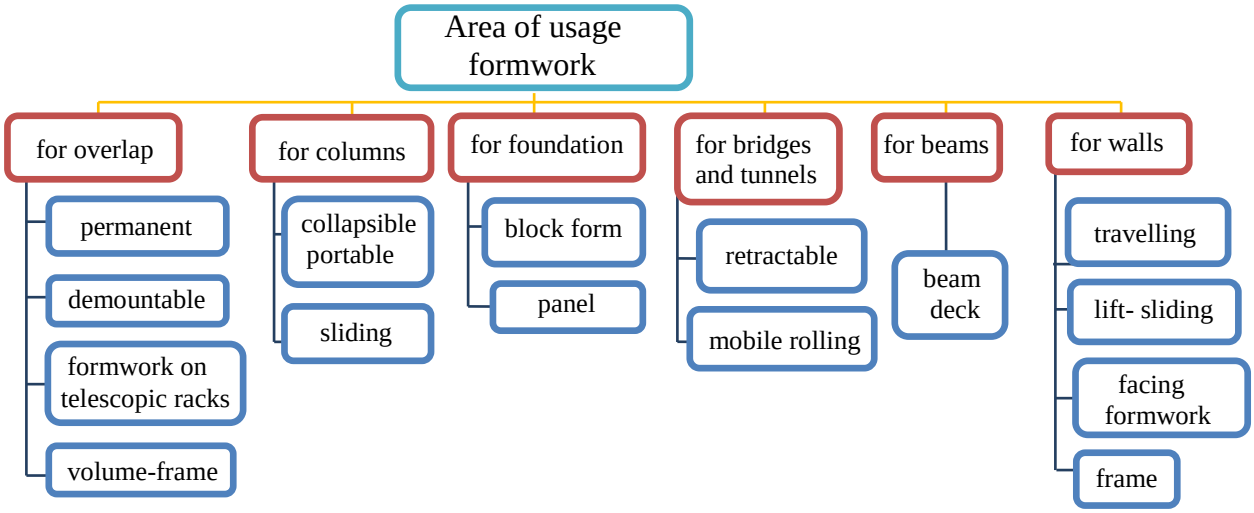


Fig. 2. Area of modern formwork usage

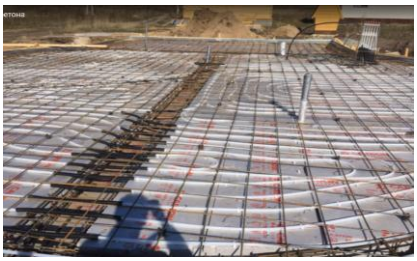
As an example, consider pneumatic formwork indicating positive and negative moments in the process of concreting buildings and structures of complex configuration. The area of usage pneumatic formwork is the erection of structures and individual elements of a curved surface. It is effective for erection of structures in hard-to-reach places of collectors, coatings of domed structures with a diameter of up to 36 m and vaulted thin-walled structures with a span of 12 ... 18 m. It does not require large expenses for transportation, installation and operation. Advantage over other types of formwork

is low weight, high turnover and low complexity of installation and dismantling.

The technology of the formwork installation is as follows: the foundation is being erected, the pneumatic decking is laid out and attached, the reinforcement is laid, the concrete mix is supplied, covered with an elastic towel, the air is pumped into the formwork, the system rises to the design position.

The main reason for the use of monolithic reinforced concrete domes and vaults in construction is the disproportion between the optimality of thin-walled structures and the disadvantages of their construction methods, which are based largely on the experience of the construction of flat systems [1-2].

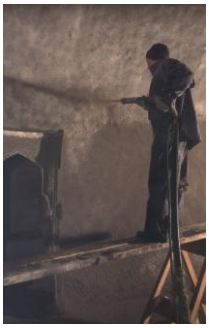
a – excavation



b – reinforcement placement

c – setting monolithic slab

d – setting formwork



e – covering of the first layer of concrete, installation of reinforcing mesh, covering of the final layer of concrete

f – general view of the building

Fig. 3. Photo-fragments of the organizational and technological sequence of works

For the construction of complex geometry buildings (Fig. 4), pneumatic pressurized systems of multilayer composite waterproofing material based on polyester fiber fabric coated on both sides with a soft PVC paste [3-5] are very efficiently used as formwork abroad. Pneumatic shells are additionally covered with PVDF-lacquer, which is antimicrobial and UV protection. The VALMEX waterproofing shell retains its operational properties in the temperature range from -40 ^{o}C to +70^{o}C.

Using of pneumatic formwork allows: to improve the quality of the concrete surface; to reduce costs and further to complete defects before construction; the construction of spatial reinforced concrete shells will cover the optimal geometric shape; to branch out construction and a poorly developed base of construction organizations; to improve the portability and timing of the dismantling.

Fig. 4. Erected outstanding buildings of complex configuration abroad

The firm specializing in the construction of monolithic domes on the pneumatic formwork is «HP Domes Inc.», Pittsburgh, USA [6]. The diameter of the erected domes is in the range of 17 to 61 m. Design projects of domes with a diameter of up to 100 m. The thickness of the shell is 7.5 ... 10.5 cm, depending on the diameter. The shell is erected to a circular reinforced concrete wall in height of 1.2 m, which perceives the coating thrust. Domes reinforcement: meridional tensile steel ropes, fixed in the base wall; ring tensioned ropes, reinforcing dome support zone; steel welded net on the entire surface of the shell. The cost of domes is from 17 to 22 dol./m^3.

In Tingley (United Kingdom) [7], a monolithic reinforced concrete dome was constructed in the Biny method on a pneumatic formwork (diameter of the dome – 32 m, lifting arm – 10 m, thickness of the shell – 10 cm, cost of a dome on 1 m^2 floor area was 50 pounds sterling).

In the United States, domes with an external heat-insulating layer are erected to pneumatic formwork [8]. Dome buildings are used to store loose materials, as coatings for water tanks and refrigeration chambers. According to specialists, it is possible to erect structures on a pneumatic formwork with a diameter from 150 to 300 m.

A dome with a diameter of 21 m was built in 1989 [9]. Pneumatic formwork from rubberized fabric weighed 1400 kg and it could be used 40 times. The shell was reinforced with prepared nets-petals. As a working armature, welded mesh 100/100/4/4 from cold drawn wire periodic profile according to GOST 23279-85 was used. In the supporting part of the dome, two grids up to 3.3 m were installed. Welded nets were separated from each other by reinforcing bars Ø 8 BSt 240 M, mounted in a circular direction in a 300 mm step. The thickness of the shell is taken 45 mm. Technical and economic indicators are given in the table.

In 1976, on a pneumatic formwork, a section of the insulated ribbed span body was erected – 12 m, length – 18 m and height at the lock – 6.1 m [10]. The vault rests on vertical walls 2,03 m high. The thickness of the slab is 30 mm, the height of the transverse ribs is 350 mm, the width of the ribs is 120 mm, the distance between the transverse ribs is 3 m. The structure of the vault, including the facing layer, the thermal insulation vapor and the reinforced the concrete mixture was raised to the design position in 45 minutes. The reinforced concrete shell was on a heated 60° C air-shaped shutter for a period of 59 hours. Technical and economic indicators are given in the table.

For the construction of monolithic wavy vaults, pneumatic formwork APV-12 [11] was used with the following characteristics: overall dimensions – 36×12×6 m; weight – 450 kg; width of the transverse wave – 3 m; lifting arm wave – 0.75 m; the size of «drunk» concreting – 24×12 m; Estimated amount of using – 20 times. Technical and economic indicators are given in the table.

Table – Technical and economic indicators erected structures in pneumatic formwork

Construction	Erection time, minutes	Labor intensity, man-hours	Material costs		Cost of construction on m^2 of floor, conditional units
			Concrete m^3 per m^2 floor	Steel, kg per m^2 floor	
Dome, diameter 21m	–	1,26	0,080	6,30	23,70
Insulated vault, 18×12m	45	–	0,053	8,30	–
Wavy vault, 24×12m	–	1,55	0,040	10,63	9,38

Conclusions and prospects for further research.

1. On the basis of learned information and practical solutions area of usage and classification systems of modern formwork was developed. It makes possible to select the necessary construction quickly, which in turn leads to a reduction in the duration of work and will reduce their cost.

2. When building erects of complex configuration, as the example indicates, it is not always effective to use standard types of formwork. This is primarily due to the weight of the formwork systems. The second indicator is the cost price of the formwork, the third is the labor intensity, and as a consequence the cost and quality of the concrete work. Therefore, a detailed analysis of formwork systems allows to select and use such formwork for buildings and structures of complex configuration that allows to reduce these indicators.

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