



An innovative solution for constructing an iron-concrete monolithic dome

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ABSTRACT:

The paper provides an innovative – simplified and economical – method for constructing a dome-shaped roof that has become quite an urgent issue due to the development in the field of construction as well as large-scale ongoing construction of churches, monastery buildings, necropolis and other domed buildings over the last years in recent years in Georgia and other countries. With respect to construction, as compared with straight-line roofing concrete and framework consumption for constructing a dome is less by approximately 25÷30%. Besides, dome-shaped roofing provides a great number of opportunities to make various architectural solutions as well as enables to maintain the architectural traditions established over the centuries. However, construction of a monolithic dome technologically is quite a complex and time-consuming process that in the first place is explained by the fact that an appropriate mold is necessary to create before. It describes a completely innovative construction of a molding system of the dome of 12 m in diameter with thin-shielded molds in levels and with an original solution of connection and fixation of the curved edges of the cathedral the second in size in Georgia on Mount Makhata in Tbilisi being under construction. As a result, along with significant saving of materials an unmolding process of the dome after it has been composed and concreted has been extremely simplified. It has been found out that by thin-shielded molds it is possible to compose separate load-bearing elements of various complexity and configuration included in the molding system. Also, the process of joining in thickened blocks of the above-mentioned elements as well as their mounting and firm fixation has been simplified. It should be noted as well unlimited possibilities of increasing extremely the features of their toughness by adding the edges of simple hardness. And what is more important, use of standard materials and molding devices significantly reduces labor and material consumption connected with formation of molds.

KEYWORDS:

dome-shaped roofing; molding system; thin-shielded molds

1. Introduction

The domes on the different buildings has many advantages, ranging from the best possible volume to surface ratio - with the minimum material consumption, maximum cubic volume is achieved. This in turn makes it possible to build a dome using fewer building materials than

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other construction forms [1]. The round shape of the dome is resistant to hurricane winds and seismic shocks. The canopy is not covered by snow, and the water flows quickly [2]. Even distribution of forces and low center of gravity make it possible to use light materials for the construction and the construction will be very durable [3]. Roof domes reduce heat gains from solar radiation, which reduces the need for cooling and improves thermal comfort in the rooms. The energy efficiency of a roof with a dome depends mainly on its form, construction and materials. Concrete in such a construction can be used in an effective form for passive cooling techniques, which can increase thermal comfort of users without energy loads from HVAC systems [4].

Monolithic system for the construction of the concrete-dome was used in cemetery chapel. The system uses soft permanent formwork in a pneumatic form. Due to the use of the method the dome is highly resistant to damage and the construction time was significantly shortened. Maintenance costs including energy for heating and cooling of the interior have been reduced which is very important for this kind of a building [5].

Some of the major challenges in the realization of iron-concrete domes is applying novel, material-effective and cost-effective forming techniques in their construction [6].

Constructing a monolithic dome is technologically quite a complicated process that in the first place is explained by the fact that an appropriate mold needs to be prepared in advance. [7, 8]. Following the existing norms of calculation and design, the main task is to maintain hardness and sustainability of a mold or molding system taking into account all kind of expecting loading [9, 10].

2. Monolithic iron-concrete construction domes

A dome mold actually represents an independent construction and it can be basically made of wood or metal - solid and dismantling. Table 1 provides several examples in this regard. Over the last years pneumatic (inflatable) molds have been in use. Table 1 provides several examples in this regard. Based on the existing experience there should have been made the most efficient decision about preparing a dome mold with a 12 m diameter for the cathedral being under construction on Mount Makhata in Tbilisi [11-14].

3. New type of monolithic reinforced concrete dome molding

As a result of analyzing the values of their constructional and technical-economical parameters there has been found a completely new solution for constructing a molding system with thin-shielded molds. It was fully constructed in the carpenter's workshop and afterwards was disassembled to eliminate lifting-transportation problems and was transferred in separate parts directly to the working place.

In order to obtain a proved solution for composing a new type molding system, a model of main framework of a dome mold was made as compared with natural sizes on a scale 1/10 (Fig. 1). Constructing a three-level dismantling and movable molding system appeared to be the most acceptable that has been easily implemented. The process of composing a solid iron-concrete monolithic dome can be divided in three stages:

According to the dome diameter, a supporting circular bottom of the whole molding system was constructed with laminated shields and flanks of 20 mm in thickness (Fig. 2).

Table 1
Different molds for constructing monolithic iron-concrete dome

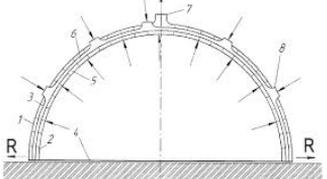
No.	Name of mold	Image or scheme	Assessment
1	Wood, solid		<ol style="list-style-type: none"> 1. Easy to construct on the constructing area, but is used to construct domes with small diameters (not exceeding 6-8 m); 2. Easy to lift and move this kind of mold and install on the mounting area, but it is difficult to unmold it.
2	Metal, solid		<ol style="list-style-type: none"> 1. Is made in a factory for constructing domes of any diameter; 2. The more the diameter and mass of a dome is, the more difficult is to lift, transfer and install it; 3. It is particularly difficult to dismantle it after it has been concreted as it is not easy for a crane to approach.
3	Wood, Dismantling		<ol style="list-style-type: none"> 1. As the diameter of a dome increases, it becomes more difficult to arrange its supporting structure as it requires great hardness and material consumption; 2. It is difficult to lift and transfer it, flanking is possible only after it will be installed on site; 3. While arranging factory-furnished shields it is necessary to construct a complex supporting system. It is difficult to receive right flatness and unmold after concreting.
4	Metal, Dismantling		<ol style="list-style-type: none"> 1. Is made in a factory, but after assembling on site it requires difficult operations of flanking; 2. It is difficult to dismantle it after concreting a dome as it is not easy for a crane to approach it.
5	Pneumatic		<ol style="list-style-type: none"> 1. Is used only in special cases and is very difficult for working at a high altitude; 2. It is particularly difficult to carry out concreting due to a bad adhesion with concrete.



Fig. 1. Model of a main framework for a dome molding system



Fig. 2. Circular bottom for composing a mold

1. One of the main tasks was to compose a crossed directing half-circular edges with inner radius of the dome. Only after their installing it was possible to create the whole molding system. Four rimmed edges in 30 cm width of the dome shape was made with doubled laminated flanks and 3 cm thickness wood flank pads. Rimmed edges were reinforced with additional wood slats for increasing their hardness (Fig. 3).
2. Connection and installation of circular edges was solved in an original way. Each of them was fixed on a circular bottom. In the central part for sticking rimmed edges a crossed unit made of metal paper was placed on a special table (Fig. 4). Apart from the center of the system it was a support platform for four edges as well.



Fig. 3. Setting up half-circular edges



Fig. 4. Special unit connecting rimmed edges

3. Main load-bearing elements of the first-level framework of the molding system were installed in the quarter of the supporting circle separated with directing edges. These elements of dome and trapezoid shape were being made by using wood slats and laminated shields. They were fixed on the circular bottom and in the upper part were united with circular laminated slats of the second level (Fig. 5).



Fig. 5. Disposition of main load-bearing elements of the first level



Fig. 6. Flanking of the blocks of the first level

4. For providing an appropriate hardness to the molding system narrow edges of additional hardness were placed between the load-bearing elements of the first level. They were fixed between the slats of the first and second levels and a molding block of the first level was completed by flanking.
5. Production of the load-bearing elements for the second level was implemented in a similar way as it was in the case of the first level with flat frames of appropriate curves. Besides, two double frames initially were joined in small space blocks and in order to increase the hardness of the blocks narrow hardness edges were installed in here as well. The blocks were disposed and fixed between the supporting circles of the second and third levels.
7. Triangle hardness edges of remaining curves of the third level were directly held by the supporting circle of the third level and their ends were gathered in the upper part, around the center of the molding system. After constructing the framework of the molding system their geometrical sizes and hardness were checked in the carpenter's workshop. The whole system was dismantled and transferred directly to the working place in separate parts.
8. A place for constructing a dome was prepared and equipped with flanked floor supported with scaffolds. Levels of the flanked floor were checked by surveying instruments and appropriate grids were marked. A framework of the molding system was constructed in the same sequence as it was done in the carpenter's workshop (Figs. 7-9).



Fig. 7. Constructing a first level of the dome on the working place



Fig. 8. Disposing blocks of a second level



Fig. 9. Disposing elements of the third level

9. After covering the molding system with the area of 226 m² with flanks of 8 mm in thickness it was reinforced and concreted. Concrete was provided with a crane in small amounts. In order to maintain a concrete layer of 20 cm in thickness on the sloping surfaces wire technological nets were used which eliminated the necessity of arranging a mutual mold (Fig. 10).



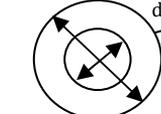
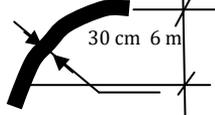
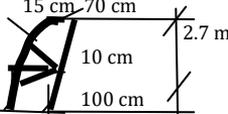
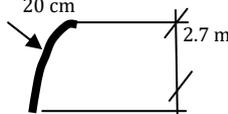
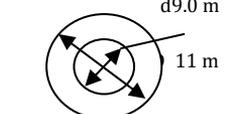
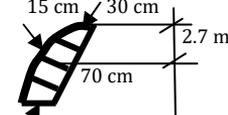
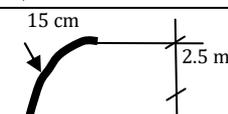
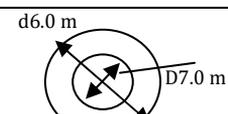
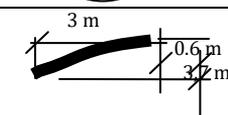
Fig. 10. Dome concreting

4. The amount of material consumption required for the new dome molding system

It should be noted that by three-level solution of the dome framework and using main load-bearing elements obtained by connecting laminates and flanks of 30 mm in thickness, consumption of the material required for constructing a molding system significantly reduced as compared with the other domes to be constructed with the same diameter. It totally made up

9,516 cubic meter flank of 30 mm in thickness and 489,34 square meter laminate (Table 2). Due to the small weight and convenient sizes of the constituent elements production/installation and afterwards, what is more important, unmolding of the framework of the molding system was implemented very quickly.

Table 2
Material consumption for the formwork for dome molding

No.	Element	Expression and size	Amount, unit	Material and consumption	Basic material consumption	
					Laminate [m ²]	Laminate [m ²]
1	Supporting circle	 d10 m D12 m	1	1. Laminate - 34.54 m ² 2. Flank - 30 mm in thickness, 1.04 m ³	34.54	1.04
2	Principal edge	 30 cm 6 m	4	1. Laminate - 3.6 m ² 2. Flank - 30 mm in thickness, 0.54 m ³	14.4	2.16
3	Load-bearing edge of the first level	 15 cm-70 cm 10 cm 100 cm	32	1. Laminate - 2.3 m ² 2. Flank - 30 mm in thickness, 0.042 m ³	73.6	1.344
4	Edges of the first level	 20 cm 2.7 m	84	1. Laminate - 1.2 m ² 2. Flank - 30 mm in thickness, 0.018 m ³	100.8	1.512
5	Circle of the second level	 d9.0 m 11 m	1	1. Laminate - 31.4 m ²	31.4	
6	Load-bearing edge of the second level	 15 cm / 30 cm 70 cm 2.7 m	40	1. Laminate - 2.1 m ² 2. Flank - 30 mm in thickness, 0.045 m ³	84	1.8
7	Edges of the second level	 15 cm 2.5 m	84	1. Laminate 0,9 m ² 2. Flank - 30 mm in thickness, 0.012 m ²	75.6	1.01
8	Circle of the third level	 d6.0 m D7.0 m	1	1. Laminate - 10.2 m ²	10.2	
9	Edges of the third level	 3 m 0.6 m 3.2 m	54	1. Laminate - 1.2 m ² 2. Flank - 30 mm in thickness, 0.012 m ³	64.8	0.65
Total basic material consumption					489.34	9.516

5. Conclusions

1. For selecting a mold system of the monolithic iron-concrete dome of a large diameter it is extremely efficient to comprehensively study and investigate its reduced model. In this peculiar case construction of a three-level dismantling/movable mold system by using thin-shielded mold appeared to be the most reasonable. As a result, along with significant saving of materials its unmolding procedure after setting up a dome and concreting it was simplified.
2. With thin-shielded molds it is possible to construct separate load-bearing elements of various complexities and configuration included in the molding system. A procedure of joining the above-mentioned elements in thickened blocks, mounting and fixing them firmly is simplified as well. This enables the molding system to be completely disassembled after it has been assembled at the carpenter's workshop and its separate elements to be transferred to the working place and reassembled on site without any trouble.
3. Along with the simplified procedure of disassembling and assembling of the molding systems it should be noted as well unlimited possibilities of increasing significantly features of their toughness by adding the edges of simple hardness. What is more important, the use of standard materials and molding devices extremely decreases labor and material consumption connected with constructing molds. Besides, their unmolding process after the dome has been concreted is carried out in a very simple manner when it becomes impossible to utilize a tower crane.

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Innowacyjne rozwiązanie technologiczne monolitycznej kopuły żelbetowej

STRESZCZENIE:

W artykule zaprezentowano innowacyjną metodę wznoszenia kopuły żelbetowej, pozwalającą uzyskać oszczędności finansowe i skrócić czas jej realizacji w porównaniu do innych technologii. Rozwiązanie wychodzi naprzeciw aktualnym tendencjom rozwoju budownictwa, zakładającym poszukiwanie rozwiązań materiało- i energooszczędnych. Ma ono również istotne znaczenie w związku z obserwowanymi w ostatnich latach wieloma realizacjami obiektów, takich jak: cerkwie, kościoły, klasztory i inne budynki z kopułami, powstającymi tak w Gruzji, jak i innych krajach. W odniesieniu do danego typu konstrukcji, w porównaniu z dachami płaskimi, zużycie materiału jest mniejsze o około 25÷30%. Poza tym dachy w kształcie kopuły dają wiele możliwości tworzenia różnorodnych rozwiązań architektonicznych, a także pozwalają zachować tradycyjne formy architektoniczne. Jednakże budowa monolitycznej kopuły jest procesem dość złożonym i czasochłonnym, który przede wszystkim związany jest z koniecznością wcześniejszego stworzenia odpowiedniego szalunku. W pracy opisana została innowacyjna konstrukcja szalunku i systemu formowania kopuły o średnicy 12 m z wykorzystaniem cienkościennych form oraz nowy sposób łączenia i mocowania tych elementów, wdrożona przy wznoszeniu katedry na Górze Makhata, w pobliżu Tbilisi. Dzięki zastosowanemu rozwiązaniu uzyskano znaczące oszczędności materiałowe, a proces realizacji kopuły, uwzględniając etap szalowania i betonowania, został znacznie uproszczony. Stwierdzono, że dzięki cienkościennym elementom szalunkowym możliwe jest wykonywanie oddzielnych elementów nośnych o różnym kształcie i konfiguracji, w procesie ich formowania. Zaproponowano również usprawnienie procesu łączenia elementów w przypadku konieczności ich pogrubienia. Zwrócono uwagę na nieograniczone możliwości znacznego zwiększania właściwości wytrzymałościowych konstrukcji przez zastosowanie prostego elementu łącznikowego na krańcach szalunku. Zastosowanie w konstrukcji szalunku typowych materiałów i urządzeń do jego wykonania znacznie obniżyło koszty robocizny i zużycie materiałów związane z wykonaniem form.

SŁOWA KLUCZOWE:

pokrycia dachowe w kształcie kopuły; system szalowania; szalunek cienkowarstwowy