

Rapid assessment of the economic efficiency of domes of buildings

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Abstract. In this article, proposals are presented on the scientifically substantiated choice of most cost-effective version of the metal domes of the building from a number of alternative designs that differ from each other in a constructive form. Proposals are to modify Professor Ya. M. Likhtarnikov's methodology to determine the labor intensity and cost of manufacturing of metal building structures. The authors propose that introducing predetermined weighting factors, to determine the future cost of constructing a building. This approach allows us to get an idea of the economic effectiveness of the coating design in the early stages of design. An algorithm for determining the weight coefficients for metal coatings is presented. In order to generalize the given methodology, the authors propose to make standardization of technical and economic indicators of domed structures. As a result of the normalization of the indicators for different variants of constructions, a formula is derived for an operative estimate of the value of any dome from one generalized.

1. Introduction

An important direction to improve the efficiency of construction is the using of light spatial structures [1] - [6], for example, mesh shells and domes. The higher effectiveness of using of these structures in comparison with traditional rack and beam systems is due to the reduction in the material consumption of the supporting frame, reduction in the labor intensity of manufacturing and installation, ability to cover both small and large spans, and to create buildings of high architectural expressiveness [7].

The speed of designing and constructing buildings increases every decade. The pace of constructing increases, what leads to the need for rapid decision-making, including the assessment of economic feasibility of using of certain structures in the building, which is being constructing. Because of increasing the pace of constructing, it becomes very valuable to be able to make an operative decision on the effectiveness of using a particular structure of the building cover at the stage of the idea's inception, before the design work. This opportunity opens up the prospect of saving funds for construction and design, by eliminating the least cost-effective design solutions, unless their application is dictated by any other factors (for example, the presence of well-established local production, architectural features, aesthetic requirements, etc.). The creation of a methodology for the rapid assessment of the effectiveness of the domed building cover on the basis of the generalized parameter - the weight of the structure, is an relevant task.

2. Materials and methods

According to the book [5], the weight of structures can be considered as a parameter of its effectiveness. It is connected to the fact that the set of other characteristics of a design depends on



weight. Weight defines the number of the operations connected with movement of designs and making it details so, can be used as an indicator of labor input of production and installation. Weight characterizes the sizes of a design, influences labor input of operations of assembly and labor input of transportation. Decreasing weight without complication of a design leads to reduce labor input. Number of details is the indicator of defining labor input of production of designs. The volume of such technological operations depends on marking, basting, cutting, editing, assembly. Considerable impact on the size of labor input of production of designs is exerted by existence of openings and welded seams. Even small quantity of them has significant effect on labor input of processing, because it involves significant increase in auxiliary time. The concept of labor input of production of a detail can be treated as the time, which was spent by the worker for its production with using machines, mechanisms and devices. All time, which is necessary for production a detail, can be spread out to the main and auxiliary time. The main time is that time which was spent by workers for directly process of production a detail on the concrete equipment. Auxiliary time is time, that is necessary for preparation and setup of the machine, movement of semi-finished products and materials from places of warehousing to the place of production a detail, time for installation and fixing semi-finished products in the machine, time for extracting a ready detail from the machine, time for cleaning and service the machine after extraction of a detail, etc. With increasing the number of identical parts manufactured on the same machine, the laboriousness manufacturing one part reduces. Decrease in labor input connected to reduction of time for performance of auxiliary operations. In this case, the seriality production of details causes positive impact on decreasing labor input.

The shape of details and shape of the design collected on their basis depend on a used type of metal. The technology of work for production separate details and for association of details in a uniform design depends on type of used metal. The shape of a sheet detail as a part of the majority of designs is close to a rectangle. The labor input of production of a sheet detail consists of time spent for a marking and cutting. The labor input of production, assembly and welding of products from sheet details depends mainly on detail perimeter. The profile detail (a corner, the I-type, a channel, a pipe and other) has one primary size - length. Assembling and welding designs from profile details is other than assembling and welding of sheet designs. This causes a difference in labor inputs of production of a sheet and profile detail, this mean it causes dependence of labor input on a detail form. As for the sheet parts, they have a huge difference from profiled parts: it is not possible to allocate the main size of them. All three sizes of the sheet metal part are important for estimating labor intensity. For example, for the details having the form of the extended rectangle, the labor input is higher, than for the details close in a form to a square [8]. At the same time, the labor input of work with a thick sheet is more than for a detail of smaller thickness.

The labor input of assembly of designs from profile details consists of time for movement of a detail, its installation for the place and temporary fixing. The specified time depends on the size of a detail (dimensions and the sizes of section), so in proportion to the weight of a detail. The labor input of welding depends on the type of a welded seam (a butt-welded seam, an angular welded seam), on the dimensions of cross section of a welded seam and on a welding method. The labor input of production of all design is equal to the sum of labor inputs operations of processing, assembly and welding (1).

$$T = T_{labor} + T_{assembly} + T_{weld} \quad (1)$$

The complexity of processing (T_{labor}) and assembly ($T_{assembly}$) depends on the weight of a detail and number of parts. The complexity of welding (T_{weld}) depends on the load and the dimensions of the structure.

The cost of production of a design (C_{prod}) can be determined by multiplication of sizes labor input (T) and the salary of workers (S_1):

$$C_{prod} = T \times S_1 \quad (2)$$

The cost of materials (C_{mass}), is equal to multiplication of total mass of material (M) on the material unit price (S_2):

$$C_{mass} = M \times S_2 \quad (3)$$

The total cost of a design (C) is equal to sum of previous components:

$$C = C_{prod} + C_{mass} \quad (4)$$

The formula (4) can be used only after end of all development stages of the project design. And it is possible to choose cheaper design from several options only after calculation the cost of each of them. So for choosing favorable option of a design it is necessary to execute design developments of a set of options, to calculate their cost, and then to compare each of them with other.

It is obvious that at an early stage of design there is no opportunity to tell in advance, which option of the metal domes, which differ only in the scheme (ridge, ridge and ring, mesh, etc.), will be the cheapest at production. To answer this question, it is necessary to execute the complete design of all variants, that we chose, and then to calculate their material intensity, labor intensity and, ultimately, the cost of each design variant. Now, the only way to speed up the process of early evaluation of the value of non-existent construction is to compare it with the realized analogs. This comparison is not always possible, because dome coverings are often "unique" products, and direct analogues with a full set of required characteristics are difficult to find. It is difficult to make use of direct or proportional determination of the value of a known, implemented prototype due to the presence of a number of unequal parameters that affect both the technical and economic characteristics of the structure. Dome building covers with a complete analogy of geometry are very rare. There are mandatory differences in the diameter of the base, the curvature of the surface, the height of the lift, etc. In addition to geometric parameters, constructive (quantity, dimensions, device of nodal connections of elements, parameters of the elements themselves, etc.) and economic (labor intensity, cost of materials, connection elements and other) parameters are very different. Due to the foregoing, the practice of choosing the best design variant from several alternative designed options has been established in the construction industry. Such a method of assessing the economic efficiency of structures has a number of flaws, although it is the only possibility of choosing to implement a more advantageous design variant in practice. The main disadvantages of the variant design method is the need for temporary and economic costs for the full design of many variants of the same building structure, as well as the limited number of design options considered by the temporary, labor and economic framework. For relatively small and relatively simple designs, variant design is not used at all. Often, for these conditions, it turns out that the desire to save money on choosing the most effective version of a simple building structure leads to comparable costs for finding the most effective option. As a result, it can be concluded in early stages of assessing the effectiveness of the future building structure in general and the metal dome cover in particular has no reliable scientific justification.

In view of what was said, today the practice of preliminary estimation of the cost of metal structures based on the total weight is applied in construction. The laboriousness of making structures is estimated as a certain percentage of the cost of metal. This method has disadvantages, the main of which is unreasonable designation of a share of manufacturing costs in the total cost of the structure. It is known that the laboriousness of manufacturing depends on the complexity of the construction. Depending on the design form, the complexity of manufacturing (and the cost of work) can differ at times. Consequently, an unreasonable choice of the share of costs for the manufacture of a structure can lead to significant errors in its final cost.

Authors suggest creating the simplified technique of operational assessment of comparative efficiency of similar designs as the solution of the described problem. Authors suggest upgrading the known technique of assessment of technical and economic indicators of metal designs. Authors propose to set of the known designs of domes it is necessary to calculate their cost. For this purpose it is possible to use any known technique, for example, the technique stated in books [7, 8]. The counted set of domes has to be broken into classes by criterion of the constructive scheme, for example, it is necessary to allocate ridge, ridge and ring, mesh, etc. Each class of domes should be subjected to statistical processing for obtaining the given values of their cost. Then it is necessary to count rationing of their technical and economic indicators in relation to the most expensive of the calculated options. As a result of a regulation it is possible to receive cost coefficients, that will consider reasonable difference in the cost of production their considered options of domes. It is possible to receive total cost of dome by simple multiplication of coefficient by the weight of metal demanded on his production, having such coefficients. Authors suggest to use a formula (5) instead of a formula (4).

$$C = C_{normi} \times M, \quad (5)$$

(C) is the total cost; (C_{normi}) - rated coefficient of each option of a dome; (M) - the weight of metal on production of a design.

The offered formula is simple in use and can be applied at the earliest design stage of a design. For determination of cost of a dome with use of the offered formula (5) it is necessary to know only two things about a design – its weight and the rated coefficient corresponding to a class of which the scheme of a dome belongs. Usability of the offered formula is that for estimation of cost of a design there is no need to know about its such details as: a design of nodal connections, details of knots, details of elements, quantity of bolts in knots, the number of welding and other.

Degree of reliability of the received decision will be defined by quantity of options of the domes entered into consideration when determining rated coefficients.

The example, is showed further illustrating an algorithm of calculation of rated coefficients by the technique offered by authors for three options of a dome of Orthodox church is presented.

3. Results

Authors have developed projects of three options of domes for the same building. Initial conditions of design were accepted identical to all three options, for example, identical were accepted geometry (diameter, height and other), material of elements, a form of cross section of elements and loads of a dome, etc. Differences between options consists only in schemes of domes. We have chosen three schemes of domes (Figure 1).

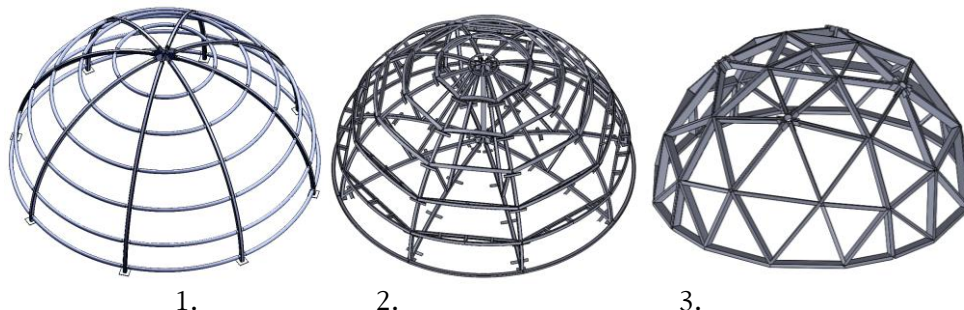


Figure 1. Variants of constructional shapes of domes

1 - ribbed-annular; 2 - latticed; 3 - mesh geodetic

Each designed dome was developed to a stage of the working project. Sections of the elements making a dome being determined. Knots of connection of elements among themselves were

developed. Bolted and welded connections of elements were calculated. After development of all details of a dome, the weight of each of three options of a dome was calculated. When determining cost of the received options of a dome calculations of labor input of production according to a technique was made [7]. The cost of materials, working costs on production and the total cost of a dome (fig. 2-5) were calculated.

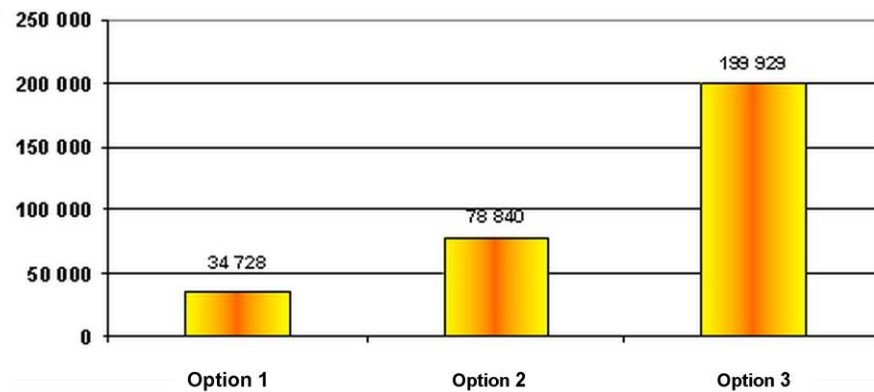


Figure 2. Production cost

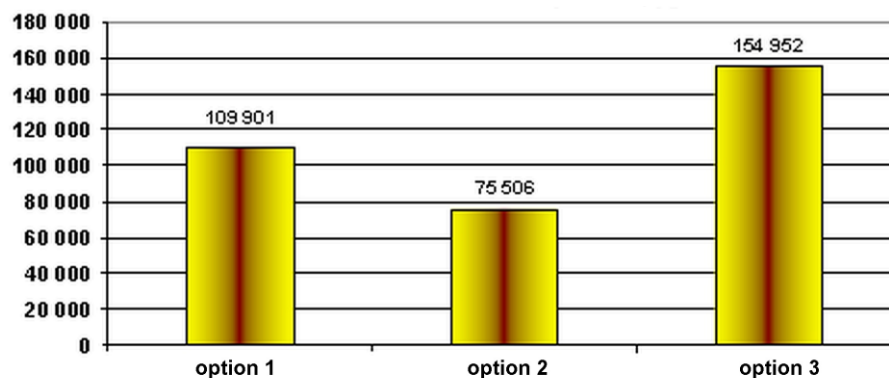


Figure 3. Cost of the main materials

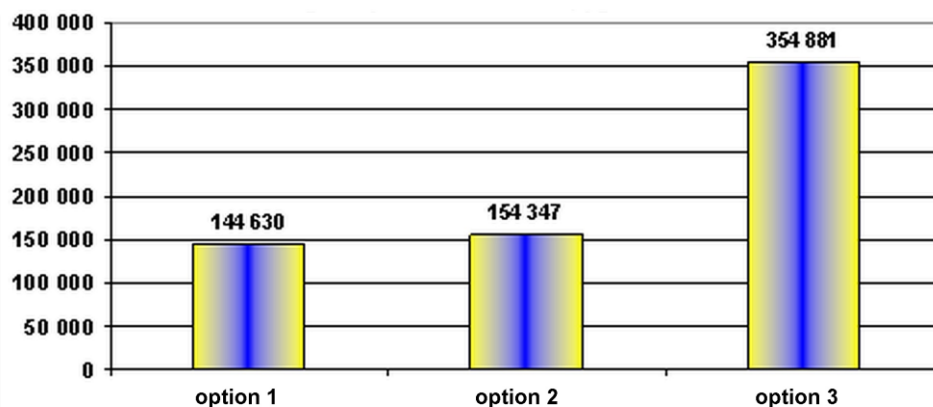


Figure 4. Total cost

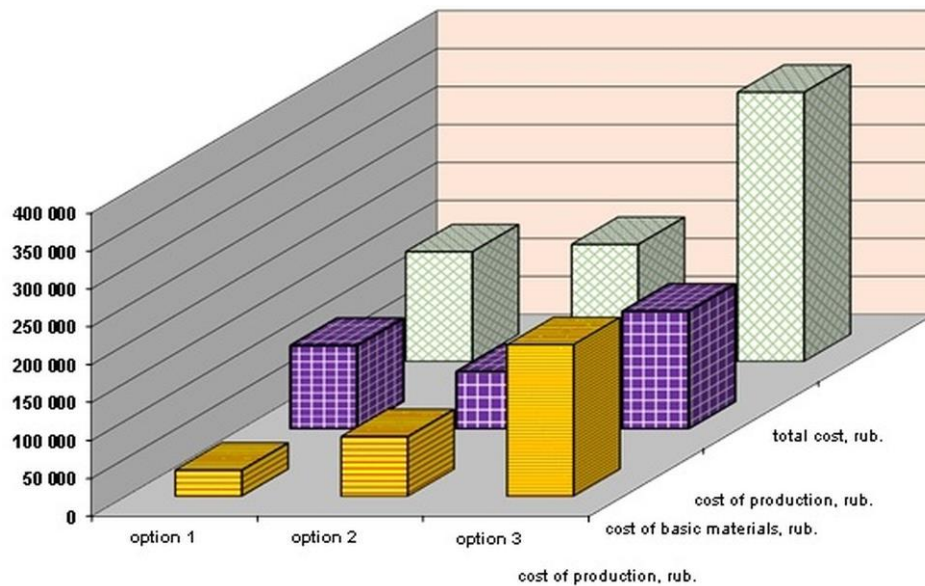


Figure 5. The chart of cost for three options of a dome

Then, coefficients, without dimension were calculated by normalizing the cost of each option to the cost of the most expensive of them (Table 1).

Table 1. Calculation of rated coefficients

Option	The name of the structural form of the dome	The total cost	
		Absolute value, rub.	The normalized value (C_{norm})
1	ribbed-annular	144 630	0.408
2	latticed	154 347	0.435
3	mesh geodetic	354 881	1

The described example is presented only for an illustration the opportunity of using the offered technique. The presented example is limited by only three options of design of domes. The example is deprived of the statistical material allowing to reduce influence of a set of individual parameters of each option of a dome on the size of rated coefficient. For obtaining objective value of cost of a design when using of the offered technique it is necessary to previously calculate reliable dimensions of rated coefficients previously. For this purpose it is required to perform work on calculation of statistically reliable coefficients on the basis of calculation of authentically large number of options of domes.

Conclusions

1. The technique allows making a reasonable choice of design of any option of a design based on knowledge of its necessary cost.
2. The offered technique has the simplified character of estimation of cost of a design before the end of process of its design.

3. Accuracy of determination of the predicted cost of future design depends on degree of reliability of the calculated rated coefficients.

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