Economic effectiveness of traditional building materials in modern conditions

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Abstract. The article studies the effectiveness of different materials usage in building structures. Specific researches and estimates have been done to complete this study. Economic usage indicators of materials with different properties for creation of identical building structures were compared. Impact of the following material properties such as strength, elastic modulus, weight and cost on the construction cost was estimated. Rafter construction was selected as a study object. Calculations examples of rafter constructions made of wood and steel are described in the paper. Material properties impact on operational characteristics of the building structures was estimated. Variant design and optimal design of constructions made of materials that properties considerably differ were reviewed. Variant design example used in the building practice was described.

Introduction

In modern conditions, building project economic attractiveness often takes priority over other effectiveness criteria. Construction economic attractiveness depends mostly on materials used to make it. Load-bearing structure cost can be reduced by using materials with the most appropriate properties. Material selection is the question of optimal material usage. The material selection problem can be solved by using variant or optimal design [1-5].

Mathematical model is created to get the best solution in case of optimal design usage. It allows selecting the best solution from a multitude of possible solutions. Selection is based on a specific predefined effectiveness criterion. Construction design based on mathematical regularity that describes properties of a real physical object is an ability to define undoubtedly the best construction. Nowadays there is no universal design methodic that could allow making optimal design of any building structure. Considering this, designers do variant design.

In variant design several alternative projects are developed. They differ one from another. Projects development continues until it is possible to define the key technical and economic indices. Project estimation criterion is very important. The criterion should be set up at the start point. The best project selection will be based on this criterion. For example, the project that has the least cost or the simplest technology of its producing and so on can be the best one.
Variant design implies competition. At the same time, variant design does not resolve the issue of the best construction finding. In variant design, only few constructions are defined as acceptable. Many options are not taken into consideration. Perhaps, options that are more beneficial are not taken into consideration. Variant design is used because it is simpler than optimal design. However, only the optimal design methods development will allow obtaining objective reply to the construction effectiveness question.

Issues related to the rational materials selection in construction are given great consideration. Significant body of technical and scientific literature provides information on the rational selection of various materials in construction [6-10].

Some construction materials are unusable or irrational in some types of constructions. For example, timber is not recommended to use in foundations, underground constructions with a changing groundwater level. It can be explained by the risk of the timber decay. However, nowadays-existing timber treatment techniques allow significantly changing material properties. Timber treatment, for example, high-pressure impregnation can significantly increase timber resistance to decay. As a result, timber gets gains new properties. It is possible to talk about introducing of a new construction material with new properties. This type of treatment causes great material cost increasing. According to the Canadian construction company CWFHC [11] such treatment cost can be 40-60% of timber cost. At the same time in underground constructions, stone and concrete materials can be used, since they do not require treatment of specific types.

Some materials in building can be replaced by each other. However, constructions made of these materials can significantly differ in their physical and economic indicators. Building constructions, cost depends on the material cost and on the production cost. Both components depend on the technical territory development where the construction is produced. Thus, an opinion on the effectiveness of interchangeable materials can be designed only by comparing them. Comparing is possible in variant design [7].

Steel and timber can be considered as interchangeable in constructions of small span buildings roofs. Historically, timber was the earlier material used for rafter constructions. Some time ago, the metal constructions cost in Russia was comparable to timber constructions. Nowadays the metal cost increases. Metal constructions cost has become much higher than the timber constructions cost. Timber is becoming a more profitable material for rafter constructions of small span in today Russian conditions.

**Materials and methods**

Calculation example of the economic timber usage effectiveness in beam constructions is provided below (refer with Figure1). Slab should be made for a building with brick walls. Construction span is 6 m. Let us assume that the beam spacing is 1500 mm. Let assume that the design load on the slab is 5 kPa. Steel design bend strength is 240 mPa. Timber design bend strength is 16 mPa.
Figure 1. Calculations example of the beam constructions

The design load on one beam is \( q = 5 \cdot 1.5 = 7.5 \text{kN/m} \). Bending moment in a beam is

\[ M = \frac{q \cdot L^2}{8} = \frac{7.5 \cdot 6^2}{8} = 33.75 \text{kN} \cdot \text{m}. \]

is the required section modulus of beam:

\[ W_{\text{mp}} = \frac{33.75}{240000} = 0.000140 \text{ m}^3 \text{ – for steel;} \]

\[ W_{\text{mp}} = \frac{33.75}{16000} = 0.00211 \text{ m}^3 \text{ – for timber.} \]

Choose acceptable beams:
- steel I-beam h=180 mm b=90 mm;
- timber beam 250x250 mm.

6 meters steel beam weight is 112.8 kg. Timber beam volume is 0.375 m³.

Metal consumption is usually rated in tons and timber consumption is rated in m³. In Russia, in the current conditions steel constructions cost is 750$/ton, and coniferous timber cost is 105$/m³.

Steel beam costs approximately 87$. Timber beam costs approximately 40$. Savings in the procurement are 47$ for each beam. Profit increases, if savings in transportation and installation of a lighter timber beam are taken into account. The example demonstrates that timber in beam slabs of small span is cheaper than steel.

There are examples of rafter systems for an 18 m wide building with 6m span spacing (refer with Figures 2-5).
Figure 2. Steel roof. Option 1

Figure 3. Steel roof. Option 2

Figure 4. Timber roof. Option 3
Option 1 requires building a rafter construction of steel rolled angles. Option 2 requires building a rafter construction of lightweight steel roll-formed C-sections. Options 3, 4 and 5 require building rafter constructions of timber beams and boards. They differ in geometry. The calculations are based on the same initial conditions—the roof slope, the supports location, external loads. For all the options, materials with the lowest possible strength characteristics are used. Elements are maximally unified in all the construction options. Material consumption for the rafter construction for an 18x110 m building is provided in table 1.

**Results**

**Table 1. Material consumption for the rafter construction**

| Rafter Construction Option, # | Technical and Economic Design Indicators |
|-------------------------------|------------------------------------------|
|                               | Material Consumption | Material Cost, [$] |

**Figure 5.** Timber roof. Option 4

**Figure 6.** Timber roof. Option 5
|   | 39.6 [ton] | 29700 |
|---|------------|-------|
| 2 | 29.7 [ton] | 22275 |
| 3 | 60 [m³]   | 6300  |
| 4 | 65 [m³]   | 6825  |
| 5 | 58 [m³]   | 6090  |

**Summary**

Table 1 demonstrates the following conclusions:

1. The materials need for roof manufacturing depends on the geometric scheme of the rafter structure.
2. The cost of a timber roof construction is significantly lower than the cost of a steel construction.

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