Cost-benefit analysis of the cast-in-place building framework vertical bearing structural members

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Abstract. The article features three types of construction solutions on vertical bearing members of the researched building which are compared according to the architectural, constructive and technological peculiarities of their construction. As a result of the research, the most rational technical solutions on vertical bearing members of the facility in question were established taking into account cost-benefit indicators. The work is based on the statements of the finite-element method, the ultimate-load method as well as the construction management method and brick and cast-in-place multistoried building technology.

Introduction
Well-managed design and construction of multistoried buildings has always been an acute problem comprising both technological and economic aspects [1]. It can be explained by the fact that the construction industry is highly interested in lower construction cost. Decreased cost of production of work along with the increased reliability and optimized labour costs and construction time are of great importance for a more efficient use of the capital investment and higher quality construction [2, 3].

Materials and methods
Initial structural scheme №1 – brick bearing walls, 380 mm thick.

On the basis of the structural scheme type in question it is possible to determine the quantities needed to construct vertical framework (Table 1) for one standardized floor of the building [4, 5].

Table 1. Quantities needed to construct vertical framework of the structure

| Name                              | Number, [pcs] | Height, [m] | Length, [m] | Width, [m] | Volume, [m³] |
|-----------------------------------|---------------|-------------|-------------|------------|--------------|
| Brick bearing walls (380mm)      | -             | 3.00        | 184.50      | 0.38       | 210.33       |
| Aerated concrete partition walls (100mm) | -             | 2.78        | 86.90       | 0.10       | 24.16        |
| Aerated concrete partition walls (250mm) | -             | 2.78        | 37.60       | 0.25       | 26.13        |
| Enclosure walls                   | -             | 0.00        | 0.00        | 0.00       | 0.00         |

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Thus, for one standardized floor of the block of flats constructed according to the initial (brick-wall) constructional type, the general characteristics of the floor are represented by the following values (Table 2).

| Name                                    | Square, [m$^2$] | Volume, [m$^3$] |
|-----------------------------------------|----------------|-----------------|
| Bearing brick walls (380 mm)            | 70.11          | 210.33          |
| Aerated concrete partition walls (100 mm)| 8.69           | 24.16           |
| Aerated concrete partition walls (250 mm)| 9.40           | 26.13           |
| Enclosure walls                         | 0.00           | 0.00            |
| Total square                            | 666.60         |                 |
| Total square of apartments sold on the floor | 365.23       |                 |

In the analysed model №2 – of a wall type (Figure 1) – the bearing members of the framework are 160 mm thick reinforced concrete cast-in-place walls and staircase and elevator section walls. Exterior enclosure walls, staircases, half-landings, landings, ventilation units, the roof and elevator wells remain consistent. The elevator wells are reinforced concrete cast-in-place.

**Figure 1.** Wall-type model:
Black – 160 mm cast-in-place walls; blue – 100 mm partition walls; green – 250 mm partition walls; red – 380 mm enclosure brick walls; grey – initial technical solutions for the block of flats

| Name                                    | Number, [pcs] | Height, [m] | Length, [m] | Width, [m] | Volume, [m$^3$] |
|-----------------------------------------|---------------|-------------|-------------|------------|----------------|
| Reinforced concrete cast-in-place bearing walls (160 mm) | -             | 3.00        | 167.56      | 0.16       | 80.43          |
| Aerated concrete partition walls (100 mm)          | -             | 2.78        | 91.10       | 0.10       | 25.33          |
| Aerated concrete partition walls (250 mm)          | -             | 2.78        | 39.36       | 0.25       | 27.36          |
| Enclosure walls (380 mm)                      | -             | 2.78        | 17.44       | 0.38       | 18.42          |
Thus, for one standardized floor of the block of flats constructed according to the wall constructional type, the general characteristics of the floor are represented by the following values (Table 4).

**Table 4. General characteristics of the floor**

| Name                                                      | Square, [m²] | Volume, [m³] |
|-----------------------------------------------------------|--------------|--------------|
| Reinforced concrete cast-in-place bearing walls (160 mm)  | 26.81        | 80.43        |
| Aerated concrete partition walls (100 mm)                 | 9.11         | 25.33        |
| Aerated concrete partition walls (250 mm)                 | 9.84         | 27.36        |
| Enclosure walls (380 mm)                                 | 6.63         | 18.42        |
| Total square of the floor                                 | 666.60       |              |
| Total square of apartments sold on the floor              | 391.54       |              |

In the analyzed model №3 – of a column type the bearing members of the framework are 500x500 mm section reinforced concrete cast-in-place columns of the building framework and the staircase and elevator section walls.

**Table 5. Quantities needed to construct vertical framework of the structure**

| Name                                                      | Number, [pcs] | Height, [m] | Length, [m] | Width, [m] | Volume, [m³] |
|-----------------------------------------------------------|---------------|-------------|-------------|------------|--------------|
| Reinforced concrete cast-in-place bearing walls (160 mm)  | -             | 3.00        | 61.56       | 0.16       | 29.55        |
| Bearing reinforced concrete cast-in-place columns (500x500 mm) | 15            | 3.00        | 0.50        | 0.50       | 11.25        |
| Aerated concrete partition walls (100 mm)                 | -             | 2.78        | 89.00       | 0.10       | 24.74        |
| Aerated concrete partition walls (250 mm)                 | -             | 2.78        | 98.64       | 0.25       | 68.55        |
| Enclosure walls (380 mm)                                 | -             | 2.78        | 56.32       | 0.38       | 59.49        |

Thus, for one standardized floor of the block of flats constructed according to the column type, the general characteristics of the floor are represented by the following values (Table 6).

**Table 6. General characteristics of the floor**

| Name                                                      | Square, [m²] | Volume, [m³] |
|-----------------------------------------------------------|--------------|--------------|
| Reinforced concrete cast-in-place bearing walls (160 mm)  | 9.85         | 29.55        |
| Bearing reinforced concrete cast-in-place columns (500x500 mm) | 3.75         | 11.25        |
| Aerated concrete partition walls (100 mm)                 | 8.90         | 24.74        |
| Aerated concrete partition walls (250 mm)                 | 24.66        | 68.55        |
| Enclosure walls (380 mm)                                 | 21.40        | 59.49        |
| Total square of the floor                                 | 666.60       |              |
| Total square of apartments sold on the floor              | 376.13       |              |
The data received as the result of local cost estimates with the use of Grand Smeta software for the analysis of technical and economic parameters of the structure scheme types are presented in the table [6]. The estimation of real flat areas for the analyzed constructional decisions was done, the results are shown in Table 7.

**Table 7. Comparative table of cost and labour intensity of the construction types of the building**

| Type                              | Shell and core final cost, [rub.] | Shell and core final cost, [manhour] | Final square of apartments sold on the floor, [m²] |
|-----------------------------------|-----------------------------------|--------------------------------------|-----------------------------------------------|
| Brick bearing walls               | 1,641,411                         | 1,881.2                              | 365.23                                        |
| Cast-in-place concrete walls      | 1,611,728                         | 1,279.3                              | 391.54                                        |
| Cast-in-place reinforced concrete columns | 1,280,169                         | 1,222.6                              | 376.13                                        |

Different types of construction solutions on the building based on the consistent initial space-planning decisions were analyzed in the article. Then, each type was calculated according to the ultimate and serviceability limit states in accordance with Codes of Practice 20.13330.2011 "Loads and Effects" [7]. The calculations were based on the finite element method implemented with the use of StarkES software [8, 9, 10]. The dependence function of reinforcement steel (t.) depending on both construction solution made and concrete strength, which allowed estimating the required amount of resources and the Project stage [11].

The next stage of the analysis in the article includes the estimation of the effect of the constructional type of the vertical bearing structures on the share in the cost and labour intensity of 1 m² of the sales square.

Based on the data analysis presented in the table, the graphs of the dependence of cost and labour intensity of 1 m² of the sale square on the type of vertical bearing structures were built.

**Figure 2. Effect of the type of vertical bearing structures on pricing of 1m² of sale square**

**Figure 3. Effect on labour intensity of 1 m² of sale square**
Figure 3. 1 Effect of the types of vertical bearing structures on labour intensity of 1 m² of sale square

![Diagram showing effect of types of vertical bearing structures on labour intensity](image_url)

Figure 4. 2 Type of the vertical bearing structure-average cost ratio in the price of 1 m² of sale square of the building

The analysis made it possible to determine that the brick bearing wall type has the greatest impact on the average cost of 1 m² of the sale square. The most beneficial in relation to the cost and labour intensity is the cast-in-place reinforced concrete column type of the building, which parameters are much more efficient than those of other types.

Summary

Thus, it was established that the column type of the vertical structures for the block of flats in question is the most economically reasonable and is recommended for the implementation on this object. Its share in the cost of 1 m² of sale square is about 11%, which is 4% less than for the initial type with brick bearing walls. It means that the use of the type with cast-in-place reinforced concrete columns can have higher economic effect for the building owner, which an important reason for the project adjustment.

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