Improving the manufacturability of the reinforced concrete structures production by using lightweight filling materials

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Abstract. The article shows the feasibility of improving the manufacturability of the prefabricated monolithic floors reinforced concrete structures production by reducing their own weight. In the works of the authors, the reduction of the sole weight and the cost is achieved by using the light materials filling the inter-gully space. It is proposed to use gas-concrete, polystyrene foam concrete blocks or limestone-limestone blocks as a local building material in the Crimea with such materials for the advanced system MARCO. Due to that, the cost of the interfloor overlap device has been reduced by approximately 10%. In addition, there is an additional cost reduction also due to the improved ergonomic work performance, increasing the productivity of workers by 6%. Innovative design and technological solutions are also presented, replacing the part of heavy concrete in a flat floor slab with hollow cores made of lightweight artificial materials - expanded polystyrene, polyethylene or cement wood.

Introduction

Production of the reinforced concrete floors of civilian buildings, when compared to other main elements of the supporting frame, using any known technology and work organization (factory prefabricated, monolithic, concreted in formwork or prefabricated monolithic) is characterized by significantly higher unit costs of the resources and, consequently, by their devices cost. This is due to their design work on bending, which requires the use of high-strength concrete, as well as sufficient reinforcement for the perception of the design loads. Moreover, the design loads for the precast prefabricated floor structures should also include technological, storage, installation and transport loads. And in case of a monolithic version, a large set of formwork is required, which is determined by the substantially large terms of the floors demolition start due to the need to perceive design loads immediately after stripping. That determines the relevance of further scientific research and pre-project developments aimed at reducing the overall resource consumption of the production and use of innovative structures of the reinforced concrete floors.

Analysis of publications. The stated scientific and technical problem falls within the range of tasks of the evaluation and improvement of the technological effectiveness of the design solutions, the theoretical foundations of which were developed in the former Soviet Union by Professor A.A. Gusakov [1], and today are developed in the works of his followers in his huge scientific school. First of all, the works of professors of the National Research University MSCU A.A. Volkova [2], A.V. Ginzburg [3], E.A. King [4], S.A. Sinenko [5], A.A. Lapidus [6], professors TSGASiA TS Kravchunovskaya and E.I. Hare [7], I.A. Sokolova [8] and many others.
The possibility of improving the manufacturability of the design solutions of monolithic and precast-monolithic structures of buildings and structures by studying and reducing resource costs throughout the life cycle is shown in our work [9]. The studies of the manufacturability of the disassembled-adjustable formwork systems also develop this idea [10]. The work shows the reserves for reducing the duration, laboriousness and cost of the reinforced concrete structures producing of high-rise civilian buildings through the selection and use of a more rational set of small-panel board folding formwork. But they do not stand out separately and do not focus on improving manufacturability and the floor structures themselves as the most resource-intensive and, therefore, have large reserves to reduce the unit costs.

The purpose of this scientific-applied work is to reduce the cost of the device for the interfloor reinforced concrete floors and coatings by reducing their own weight by choosing, justifying and developing the improved structural and technological systems for such floors.

The tasks of this work are determined as follows:

- The analysis of the status of the issue of improving the manufacturability of the device of the reinforced concrete floor structures with the identification of directions for their possible improvement by replacing a part of heavy concrete with hollow or solid liners of the lighter materials;
- The reasonable development of such ceilings improved designs, describing their essence and technological advantages: experimental and production studies of these structures;
- The assessment of the feasibility and effectiveness of the developments approbation to improve the technological level of the prefabricated monolithic civil engineering in the Crimea.

The solution of the tasks determines the main content of this work.

Results

The use of the multi-hollow floor slabs of the high-rise civilian buildings should be considered ubiquitous in the USSR and certainly an effective technological solution to the past. Changing the hingemovable work scheme for pinching in the monolithic supporting zone with preserving the reverse bend, it is still possible to achieve some saving of resources (licence RU No. 2617813 C2), presented in [11]. The new elaborations of the CSRIEE housing introduce the practice of high-rise civil construction of new generation houses, differing in the use of prefabricated multi-core reinforced concrete floor slabs of increased spans, thickness and carrying capacity [12]. The constraining factor in the development and distribution of such innovative structural and technological systems is the lack of domestic equipment for factory manufacturing of hollow-core reinforced concrete slabs. The simple and time-tested flow-aggregate production lines of the prestressed slabs, in most cases, were destroyed during the crisis, and the foreign-made stand-shape molding lines, although energy-efficient, require large up-front investments that can be recouped only with the mass construction of the mentioned houses new generation.

Meanwhile, the analysis of the available publications and production experience allows us to trace another trend - the development and implementation of foreign elaborations in Russia, including the replacing part of heavy concrete in interfloor flat slabs with lighter inserts made of materials of artificial origin (lightweight concrete, expanded polystyrene, cardboard, plastic, etc.). So, such examples as the theoretical and experimental studies of specialists of the Siberian Federal University (SFU) are of interest with the purpose to create a precast-monolithic construction of an interfloor overlap in which its lower part is made in the factory using the same method of continuous formless molding, and the upper one is concreted later in the project position of lighter concrete [13]. Certainly, the savings in materials and the reduction in its own weight of the structure cannot be noticeable because the lighter concrete should be replaced on the upper part of the slab and must necessarily be structural, perceiving compressive stresses in the span and tensile and tangential at the bearing sections. It is preferable to exclude or replace heavy concrete in the middle of the span and the thicker slab close to the neutral line of normal stresses. But, from the technological point of view, the possibility of simultaneously creating a heat-insulating screed immediately below the floor finish is also positive.
But in general we see the more promising structures for reinforced concrete floors with fixed formwork for bearing prefabricated monolithic beams, between which there are various inserts that replace reinforced concrete with a lighter building material, on the top of which a thin reinforced concrete slab is concreted. The substantial savings of heavy concrete are achieved by reducing the own weight of the slab, thereby reducing the design constant load on which the structure is designed. These systems include MARCO systems [14, 15], manufactured and supplied to the Russian market, for example, by Columbus, GRAS and others.

Analyzing the well-known foreign systems Porotherm, Teriva, Ytong, Rectolight, as well as the previously mentioned domestic precast monolithic system SMP MARKO (prefabricated monolithic floors - monolithic reinforced structures) created in their development, it was found that the latter is the most adapted (technologically advanced) for use in the Crimea. Its proposed modification consists in replacing the prefabricated reinforcing-shuttering block with two elements manufactured in construction conditions – the reinforcing spatial framework and the formwork board-foundation, on which a gap providing the required thickness of the protective layer of concrete, the reinforcement framework was mounted (Figure 1).

Figure 1. Elements of the prefabricated system and the obtained cross-sections of the spatial reinforcement frame of the monolithic supporting beam of the projected slab – the object of research and introduction

Such a modification makes it possible to completely eliminate transportation costs for the delivery of factory-made elements, which for the conditions of the Crimea are of great economic importance due to the range of factory production locations of such prefabricated elements and, until now, quite complex logistics. In the process of experimental implementation of the proposed technology, some time-keeping observations had been carried out, the video recording the process was carried out simultaneously by the two cameras from different points, and the physiological parameters of the state of the workers were recorded online. After processing the results of the experimental observations according to the selected methods of evaluating the ergonomics of labor [16], the severity category of labor from heavy (when setting up monolithic floors) to medium reduction was observed when performing the work on the proposed technology. This additionally gives also the substantial increase in the labor productivity of workers by 6% with a corresponding decrease in the production costs. Even more tangible will be the economic and social effect of replacing liners from local blocks of the Crimean shell rock to similar-sized blocks of aerated concrete, polystyrene concrete or even polystyrene foam.

For the structural systems of multistorey buildings with a full reinforced concrete frame and flat floor slabs, their solo weight is also reduced abroad by the replacing part with concrete with plastic liners of various shapes — balls and similar rotation bodies (Bubl Deck technology), rectangular parallelepipeds (NAUTILUS technology), etc. Moreover, in their prospectuses, the developers show up to 35% savings in reinforced concrete with other improved manufacturability indicators resulting from this. Accepting the mentioned technologies as a basis, with our participation, we have developed and patented (license RU No. 185868 U1) our own design for a composite monolithic ceiling with plastic inserts of the original shape and location (Figure 2).
Its distinctive features are both the original form of inserts in the form of a body of rotation, and the fundamental possibility of placing them in the body of a future plate in a different position, depending on the nature of the plate part work which they are located. In addition, the liners themselves are supposed to be assembled on the site of three factory-made parts - the lower and upper covers and the middle, in the form of a hollow truncated cone. That allows, in contrast to the volumetric spherical bodies, compactly pack these blanks for transportation to the object. Consequently, the proposed structural system of the flat reinforced concrete floors with the prefabricated liners made of plastic will be more technological than most of the foreign ones mentioned above. The studies conducted by Andrey Smirnov in his master’s thesis showed the competitive results: the consumption of concrete and weight is reduced by 25%, the need for reinforcing steel — by 27%, and the cost price (only due to the economy of materials) - by 20%.

The significant effect can also be obtained when using fixed formwork of fibrolite boards with glued foam polystyrene liners or the same fibrolite (concrete wooden) plates according to the VELOX technology, where these plates are called chip-cement [17]. Similar boards based on the wood chips can also be obtained using dolomite carbonate binder, developed by our scientists [18]. In addition to saving material and labor costs in the production process of the slab itself, it turns out the ceiling surface, usually requiring only finishing. What is certainly a more technological solution, as it does not provide for time-consuming and heavy wet plaster or widespread cladding with sheets of drywall. However, this constructive-technological system provides for the support of floors only on longitudinal bearing walls, i.e. works like a beam.

Its further resource-saving development seems to us its using as a slab prefabricated-monolithic floor structure, based on all four sides. The Crimea is characterized by the design and construction of monolithic antiseismic belts under or at the level of floors. The combination of a monolithic reinforced concrete belt and precast-monolithic overlap using the VELOX technology improved in this way, with its support on all its sides, will give a more substantial, synergistic effect of saving materials, first of all, heavy reinforced concrete.

![Figure 2](image)

**Figure 2.** Fragment of the overlap construction with the replacement of part of heavy concrete with plastic inserts

**Summary**

1. Replacing a part of the heavy concrete with the lighter material in the thickness of reinforced concrete floor slabs is a proven design solution that improves the manufacturability of their state.
2. Innovation development of this direction in the Republic of Crimea seems to us the most effective use for such a replacement inserts made of local materials, plastic or fixed formwork of wood concrete.

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