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## MULTI-CRITERIA ANALYSIS OF LIGHTWEIGHT MONOLITHIC OVERLAPPINGS

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**Abstract.** The blockouts and inserts in lightweight monolithic overlap setting are being analyzed in the article. The basic idea of using blackouts and inserts is reducing the mass of the construction through the removal of its concrete which does not engaged in construction work. This helps to reduce expenses on material without decreasing the bearing ability of overlap. The determination of the most effective overlap for the shopping and entertainment center "Gagarin Plaza" in the Odessa city through the multi-criteria analysis filtration. Different types of blockouts were compared such as permanent formwork in the rectangular, square, spherical shape and polystyrene foam inserts. Basic criteria are labor intensity, cost, weight of finished product. Showing results grouping and filtration of the main criteria are completed, score of each decision and the analysis of the diagrams according to the main criteria. According to the analysis results, the option of a lightweight overlap with inserts of polystyrene foam liners was chosen.

**Keywords**: monolithic overlapping, blackouts, inserts, multi-criteria analysis.

## БАГАТОКРИТЕРІАЛЬНИЙ АНАЛІЗ ПОЛЕГШЕНИХ МОНОЛІТНИХ ПЕРЕКРИТТІВ

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**Анотація.** В статті проведений аналіз пустотоутворювачів і вкладишів для влаштування монолітних полегшених перекриттів. Основна ідея застосування пустотоутворювачів та вкладишів полягає в зменшенні ваги конструкції, шляхом видалення з неї бетону, який не приймає участі в роботі конструкції. Це дає можливість зменшити затрати на матеріали, не погіршуючи при цьому несучої здатності перекриття. Визначення найбільш ефективного рішення перекриття для торгово-розважального центру «Гагарін Плаза» в м. Одесі виконано шляхом багатокритеріального аналізу варіантів. Показано результати групування та фільтрації головних критеріїв та технологій, бальна оцінка кожного рішення і аналіз діаграм по головним критеріям. По результатам аналізу вибраний варіант полегшеного перекриття з пінополістирольними вкладишами.

**Ключові слова**: монолітне перекриття, пустотоутворювачі, вкладиші, багатокритеріальний аналіз.

# МНОГОКРИТЕРИАЛЬНЫЙ АНАЛИЗ ОБЛЕГЧЕННЫХ МОНОЛИТНЫХ ПЕРЕКРЫТИЙ

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**Аннотация.** В статье проведен анализ пустотообразователей и вкладышей для устройства монолитных облегченных перекрытий. Основная идея применения пустотообразователей и вкладышей состоит в уменьшении веса конструкции, путем удаления из нее бетона, который не принимает участия в работе конструкции. Это дает возможность уменьшить затраты на материалы, не ухудшая при этом несущей способности перекрытия. Определение наиболее эффективного решения перекрытия для торгово-развлекательного центра «Гагарин Плаза» в г. Одессе выполнено путем многокритериального анализа вариантов. Показаны результаты группировки и фильтрации главных критериев, бальная оценка каждого решения и анализ диаграмм по главным критериям. По результатам анализа выбран вариант облегченного перекрытия с пенополистирольными вкладышами.

**Ключевые слова:** монолитное перекрытие, пустотообразователи, вкладыши, многокритериальный анализ.

**Introduction.** In construction practice the solid reinforced concrete overlapping in different buildings types are more often in use. According to the analysis of construction level in 2017, residential construction increased by 16.5%, non-residential – by 27.3%. This is why during the designing of heavy load slabs or spans it is needed to solve the important problem – the reduction of solid reinforced concrete overlapping own weight and material savings. This can be achieved through the insert introduction into the solid monolithic plate or using special formwork with blockouts.

**The recent research analysis.** In modern Ukrainian monolithic construction mentioned solutions almost not used which is connected with the lack of lightweight solid slabs (with inserts) construction technologies researches. There was no recommendation found about the informed choice of lightweight slabs construction and technological solutions choosing.

The thickness of "Gagarin Plaza" trade and entertainment center is 26 cm and in the capital and slab junction area – 40 cm. Savings from blackouts utilization – 3116 м$^3$ of concrete 5 608 800 UAH.

Therefore, the investigation of the most effective solution of lightweight slabs placement in the frame-monolithic building (based on the trade and entertainment "Gagarin Plaza" example) is very important and actual task.

**Objective.** The solution of the most effective version of lightweight slab for the trade and entertainment center "Gagarin Plaza" in Odessa city.

Tasks:

1. Choice of solution options for comparison.
2. Filtration of evaluation criteria.
3. Multi-criteria analysis of construction and technological solution.
4. The choice of the most effective slab solution for the trade and entertainment center "Gagarin Plaza" in Odessa city.

**Results of the study**. Nowadays in residential and industrial buildings construction, the utilization of frame schema made of monolithic reinforced concrete is mostly in use. The most massive constructions in modern buildings are flat slabs without beam. One of the main advantages

of reinforced concrete is its comparatively low price, comparatively ecological compatibility, comparatively ease of use, the possibility of complex forms arrangement of frame elements and practically unlimited material base. One of the main disadvantages of this material is its large carcass structures weight [1]. In this case, there is a possibility to reduce monolithic slab mass through the creation of inserts in them.

The use of non-removable blockouts reduces the weight of the structure by removing the material that are not engaged in the work. Reinforced concrete slabs with inserts may have a bigger bearing capacity and bending stiffness, and a weight 20-40% less than solid elements. Moreover, there is the possibility of creating spans of a larger size, reducing the overall weight of the building structure that effects on the foundation. In addition, savings are achieved by delivering fewer concrete mixes to concrete structures [2].

The trade and entertainment center "Gagarin Plaza" in Odessa is a monolithic frame construction with a beamless slab. That means that the construction and technological solution is typical nowadays. In any of these buildings, which have a significant pressure, it is advisable to consider the possibility of lightweight slabs placement.

In this work, using the multi-criteria analysis [3, 4], the technology of placement of different types of slabs with liners is compared. In Fig. 1 you can see different types of constructional and technological solutions for the installation of slabs with the liners formation using inserts and blockouts.

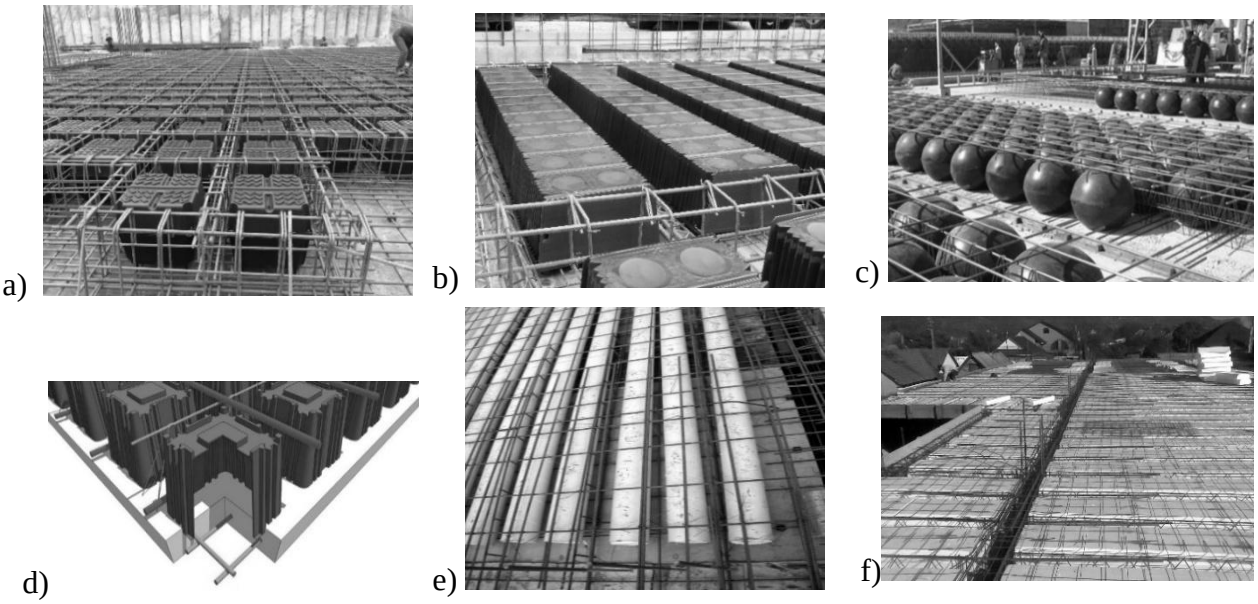


Fig. 1. Slab Liners:
a – U-BootBeton; b – U-BahnBeton; c – Buble Deck; d – Airdeck; e – cardboard tubes;
f – polystyrene foam inserts

Formwork U-Boot Beton (Fig. 1, a), produced by Italian company Daliform Group, made of recycled polypropylene and was designed to create lightweight bidirectional slabs and foundations of reinforced concrete [5].

U-Bahn Beton (Fig. 1, a), is a modular formwork made of recycled polypropylene, specially developed for the implementation of unidirectional slabs with monolithic reinforced concrete. The liner created by U-Bahn Beton can be used for wiring cables or other engineering systems [5].

Solving the mass reduction problem of the monolithic slab and simultaneous flat ceiling surface while its setting, Swiss firm "Cobiax", developed the system "Bublle Deck" (Fig.1, c). Ceiling of this system consists in armature frame, inside which hollow balls are placed, made of the

recycled secondary raw material – polyethylene. Monolithic concrete filled up all the space between balls and forms a leveled layer above them [6].

According to the Airdeck technology (Fig.1, d) the factory produces the lower edging of the slab in the form of prefabricated reinforced concrete structure with recessed plastic elements (airboxes). The slab bottom has standart sizes: thickness – 60 mm, length – 9 m and width up to 4 m [7].

For the slab's mass reduction, it is possible to make cardboard tubes (Fig. 1, e) which are soaked with hydrophobic solution. The external diameter of tubes – 150 mm. The tubes' knuckles are pressurized with plugs in the form of a special device made of a grid [8].

The use of modern thermal insulating materials with a low volume mass as a blockouts, including the polystyrene foam (Fig. 1, f) allows not only to reduce the weight of a slab but also to improve the heat and sound insulation properties of a slab. The technological process provides multilayer slab's concreter, the blocks' decomposition on the bottom layer of laid concrete and the subsequent slab concreting [8].

For making decision on blockouts choice next criteria were considered (Table 1).

Table 1 – The comparison of setting slabs technology of trade and entertainment center

| Criteria's / Technology | Concrete expenses, $m^3$ | Weight of the finished product, t | Inserts' cost, UAH | Labor intensity hum-hour | The number of inserts (thousands) | Length of working days, days | Sound insula-tion, dB |
|---|---|---|---|---|---|---|---|
| Traditional solid overlap | 11345 | 27228 | - | 11822 | - | 383 | 46 |
| Overlap with U-Bahn Beton inserts | 7488 | 17971 | 4928 | 9759 | 69,12 | 325 | 41 |
| Overlap with U-Boot Beton inserts | 7612 | 18269 | 5504 | 8694 | 41,60 | 295 | 42 |
| Overlap with Airdeck spherical inserts | 9299 | 22318 | 5280 | 10694 | 352,0 | 356 | 39 |
| Overlap with Bublle Deck inserts | 7900 | 18960 | 5056 | 9464 | 800,0 | 315 | 38 |
| Cardboard tubes | 8476 | 20342 | 1280 | 8900 | 64,0 | 298 | 40 |
| Polystyrene foam inserts | 8229 | 19749 | 1760 | 9172 | 38,40 | 306 | 38 |

The technology evaluation through the quantitative criteria based on a scale of 1 to 10 which means that 1 is a minimal scale and 10 is a maximum scale value. The rest of scores is calculated with the aid of interpolation. Structural and technological decisions, criteria and the assigned scores are set out in Table 2.

Table 2 – Scored technology evaluation

| Criterias / Technology | Concrete expenses (score) | Weight of the finished product, (score) | Inserts' cost (score) | Labor intensity (score) | The number of inserts (score) | Length of working days, (score) | Sound insula-tion, (score) |
|---|---|---|---|---|---|---|---|
| Traditional solid overlap (№1) | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Overlap with U-Bahn Beton inserts (№2) | 10 | 10 | 7 | 4 | 6 | 4 | 3 |
| Overlap with U-Boot Beton inserts (№3) | 9 | 9 | 3 | 10 | 9 | 10 | 4 |
| Overlap with Airdeck spherical inserts (№4) | 3 | 3 | 4 | 3 | 5 | 3 | 8 |
| Overlap with Bublle Deck inserts (№5) | 7 | 7 | 5 | 6 | 3 | 6 | 10 |
| Cardboard tubes (№6) | 5 | 5 | 10 | 9 | 7 | 9 | 6 |
| Polystyrene foam inserts (№7) | 6 | 6 | 9 | 7 | 10 | 7 | 10 |

To get results in the chart format (Fig. 2, 3, 4, 5), the MS Excel program is used.

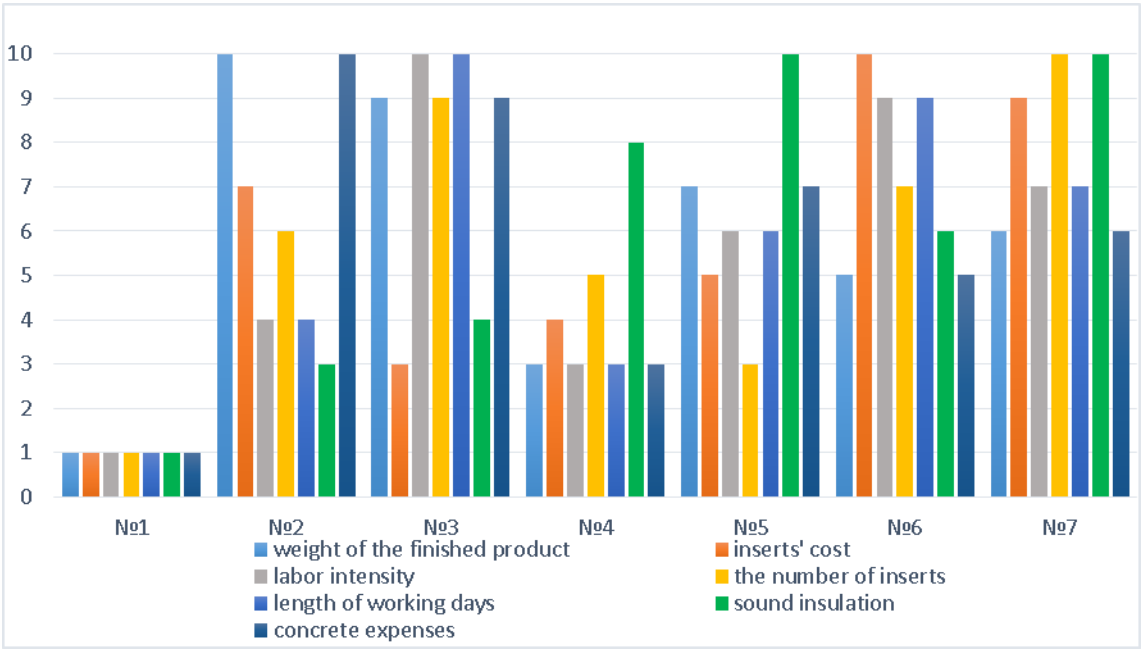


Fig. 2. Technology comparison based on 7 criterias in summary chart

The chart analysis allowed to find out the basic criteria. They are: weight, cost, concrete expenses and labor intensity. On the fig. 3 the construction and technological solutions comparison based on these criteria is showed.

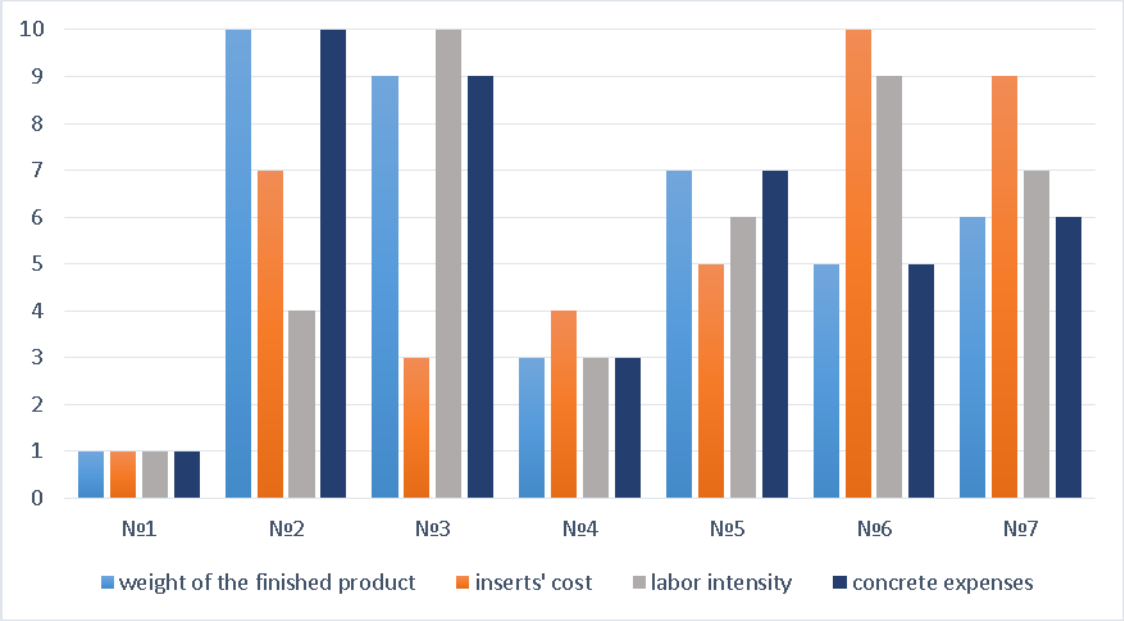


Fig. 3. The technology filtering based on main criterias

Analyzing the resulting data, it is obviously that technologies № 1 and 4 are far below the others, so they will not be considered in further (Fig. 4).

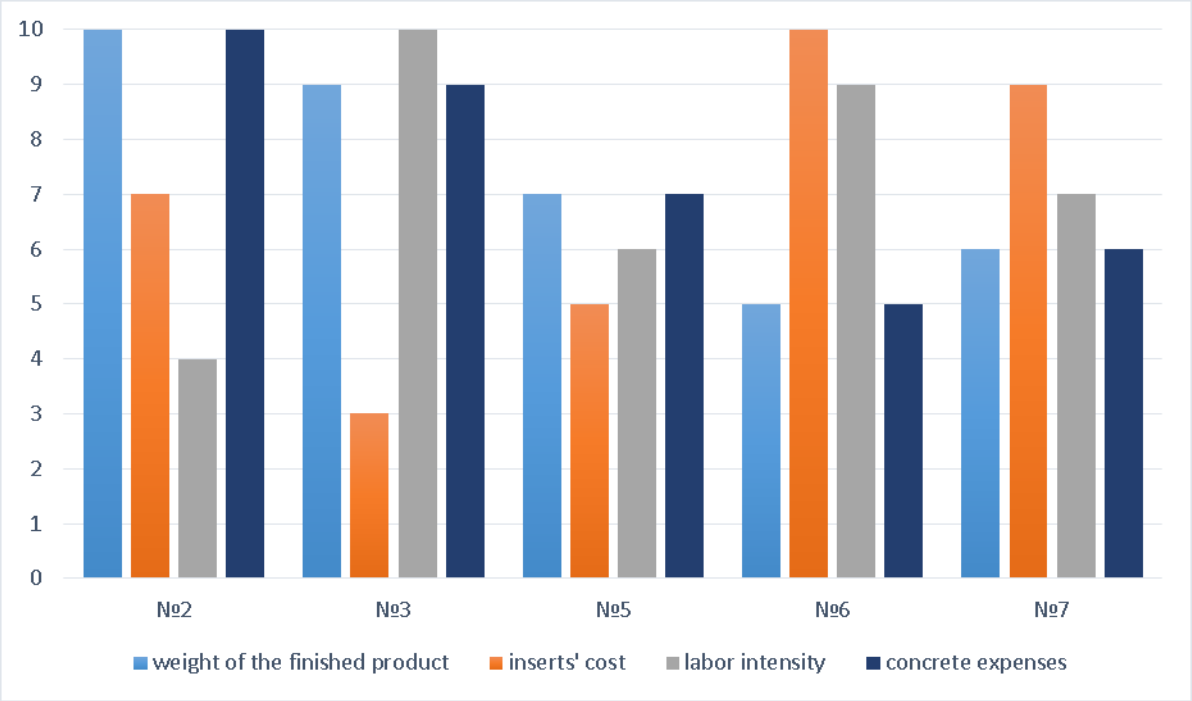


Fig. 4. Technology comparison based on main criterias

Based on received data, further we will compare two technologies which have the best ratings, they are cardboard tubes and polystyrene foam inserts (Fig. 5).

In cost-effective terms, more profitable technology is an overlapping with polystyrene foam inserts, as they have less concrete charge than in overlapping production with cardboard tubes. And the price difference in concrete use is more, than in blockouts.

Although the labor intensity of polystyrene foam inserts is higher, and cardboard tubes have a lower cost, but it is necessary to take into consideration that polystyrene foam is produced in

Ukraine, and the tubes should be ordered abroad. Analyzing the resulting data, we accept the variant of monolithic overlapping setting with blockouts made of polystyrene foam inserts.

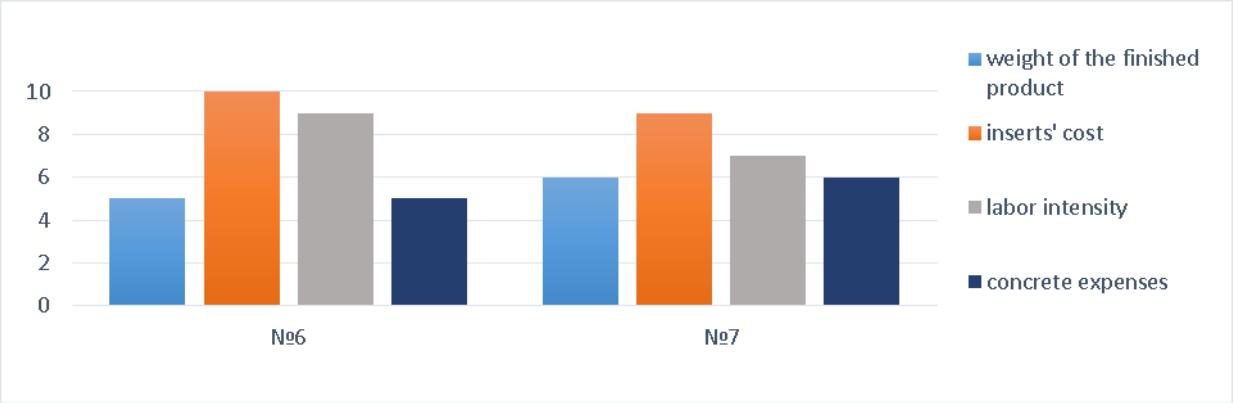


Fig. 5. The comparison of cardboard tubes and polystyrene foam inserts technology setting

**Conclusions:**

1. The technology of a lightweight slab with a foam polystyrene inserts setting is the most effective option.

2. Comparing with a traditional solid overlap, its utilization during slab setting in the trade and entertainment center “Gagarin Plaza” in Odessa allows:

– to reduce concrete costs by 27% (3116 $m^3$) which are 5 608 800 UAH considering average market prices;

– to reduce the construction’s labor intensity by 22%;

– to improve the slab’s heat and sound insulation properties.

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