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IMPACT OF GEOMETRIC SLAB PARAMETERS ON THE TECHNICAL AND ECONOMIC EFFICIENCY OF BUBBLEDECK-TYPE LIGHTWEIGHT SLABS

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Summary. This article presents the results of a numerical study on the performance of various configurations of lightweight monolithic slabs of the BubbleDeck system, which use hollow plastic ball inserts to eliminate inefficient concrete from the slab's neutral zone. This approach makes it possible to significantly reduce the weight of the structure without compromising its load-bearing capacity.

The aim of the study was to investigate the influence of geometric parameters of the slab—namely, the diameter of the plastic balls, slab height, and span—on the stress-strain behavior and techno-economic indicators of BubbleDeck-type slabs.

To achieve this goal, nine design variants of lightweight slabs were modeled using plastic balls with diameters of 180 mm, 315 mm, and 500 mm, embedded in slabs sized 6×6 m, 7×7 m, and 8×8 m, respectively. The slab height varied depending on the ball diameter, ranging from 230 mm to 600 mm. All variants were modeled in the LIRA structural analysis software. The models accounted for actual loading conditions, including self-weight, service load, and snow load.

The analysis showed that the use of plastic inserts can reduce the weight of the slab by up to 36% compared to conventional solid slabs. At the same time, deflections in all variants remained within the permissible limits. The best overall techno-economic performance was observed in the variant with 315 mm diameter balls and a 7×7 m span. In this case, the volume of concrete was reduced by 28%, and reinforcement consumption by 10–12%.

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The article also provides deformation diagrams and comparative tables of characteristics for all slab variants.

Conclusions are drawn regarding the feasibility of using the BubbleDeck system in civil building design, especially in conditions with limited foundation load capacity or when material and logistics costs need to be minimized.

Keywords: lightweight slabs; monolithic slab; plastic balls; BubbleDeck; numerical modeling

PROBLEM STATEMENT

One of the pressing issues in modern construction is the excessive weight of monolithic reinforced concrete structures, particularly monolithic floor slabs. Traditional solid monolithic slabs contain a significant volume of concrete in the central part of the cross-section, which does not actively contribute to the slab's strength and stiffness. This inefficient material distribution leads to resource overuse and increases the load on the structural frame and building foundations. As a result, additional costs are incurred during construction.

At the same time, the modern construction industry is influenced by environmental, economic, and technical factors. The growing demand for energy efficiency, reduction of carbon emissions, the need for waste recycling, and lower construction costs are driving the search for new structural solutions that can ensure a balance between reliability, cost-effectiveness, and sustainability. In this context, the BubbleDeck system has attracted considerable scientific and practical interest. This modern technology lightens monolithic slabs by inserting hollow plastic elements (typically spherical in shape) into the neutral zone of the reinforced concrete slab body.

As shown in the work of Tina Lai [1] and S.O. Buhaievskyi [2], the use of such solutions allows for a significant reduction in the self-weight of the slab (up to 40%) without compromising its strength characteristics. This creates favorable conditions for more economical design of the load-bearing frame elements and building foundations. Moreover, the possibility of manufacturing plastic balls from recycled polyethylene helps to reduce the environmental impact of the construction industry.

However, despite the obvious advantages of the BubbleDeck system, several issues remain unresolved regarding its adoption in design practice. Primarily, this concerns the lack of standardized approaches for selecting the optimal diameter of the ball inserts, depending on the slab span, its height, and the type of loading.

Often, an excessive slab thickness caused by a large ball diameter leads to inefficient use of such a structural system. In addition, engineers frequently lack sufficient information about the actual impact of the geometry of the ball inserts on deflections, crack resistance, and slab deformability.

There is a lack of systematic comparative studies in the literature that would allow for an accurate assessment of how slab stiffness and strength vary depending on its geometric parameters.

Thus, a scientific and practical task arises: to determine the optimal parameters of BubbleDeck-type lightweight monolithic slabs (insert diameter, slab thickness, span dimensions) while considering the regulatory requirements for stiffness, strength, and economic efficiency. To achieve this, it is necessary to conduct a comparative numerical analysis of several slab variants with different geometries, identify the key factors influencing the stress–strain behavior, select rational reinforcement schemes, and assess the potential material savings.

REVIEW OF PREVIOUS RESEARCH

The issue of reducing the weight of reinforced concrete slabs through the use of various types of hollow inserts, particularly plastic balls, occupies a prominent place in contemporary scientific research. Over the past decade, there has been active investigation into the efficiency of BubbleDeck-type systems, driven by both engineering advantages and the relevance of resource-saving technologies.

A number of sources (in particular, [3–5]) highlight the relevance of the issue of excessive weight in traditional reinforced concrete floor slabs. In his textbook [6], A.M. Pavlikov emphasizes the rationality of removing concrete from the neutral zone of structural elements in order to reduce the load on the foundations.

Among Ukrainian researchers, a significant contribution to the development of this topic was made by S.O. Buhaievskyi, who, in his work [2], provides a detailed classification of modern reinforced concrete lightweight slab systems with void formers, analyzes their structural behavior and technical advantages. Particular attention is paid to the various geometric shapes of inserts, especially spherical balls, as an effective way to reduce the volume of non-structural concrete.

The study by Kripak, Kolyakova, and Gaidai [7] complements the theoretical framework with a practical analysis of the effectiveness of reinforced concrete slabs with hollow inserts. The authors demonstrate that, with proper design, the weight of the structure can be reduced by up to 30% without compromising the slab's strength characteristics.

The study by Kripak, Kolyakova, and Skopets [8] is devoted to the analysis of calculation methods for such slabs. The authors compare different approaches to accounting for voids in the slab body and propose improvements to the models by considering stiffness distribution irregularities. Similar modeling challenges are addressed in the publication by Basiuk and Vylotnyk [9], who used the finite element method to develop computational models of hollow slabs. Their work confirms the feasibility and value of numerical analysis in the design of such structures.

In article [10], a flat slab with plastic spheres in the neutral axis was modeled, the stress-strain state was analyzed, and relationships between the geometry of the inserts and the distribution of bending moments were obtained.

Interest in the topic of slabs with void formers is also observed in international research. In particular, the study by Ibrahim, Ali, and Salman [11] experimentally investigated the bending capacity of two-way slabs with plastic inserts. The results confirm that the studied structure can withstand loads at the level of 80–95% compared to solid slabs, while significantly reducing weight. Similar conclusions were reported by Surendar and Ranjitham [12], where numerical and experimental modeling were combined with good agreement of results.

The study by Shetkar and Hanche [13] is devoted to the use of not only spherical but also elliptical inserts. The authors concluded that the shape of the void has a minor impact on strength but affects the overall thickness of the slab. These results may be useful for further optimization of the structural depth of the slab.

The research by Neeraj Tiwari and Sana Zafar [14] provides an analysis of the implementation of BubbleDeck slabs in high-rise construction practice. The study by Harishma and Reshmi [15] also highlights the advantages in reducing loads on foundations, particularly for large spans.

Based on the analysis of technical manuals from BubbleDeck UK [16, 17], it can be concluded that the system demonstrates high technological adaptability: it allows for the implementation of both fully monolithic and combined (prefabricated-monolithic) slab options, while providing standard solutions for reinforcement and installation.

Thus, previous studies demonstrate:

a consistent trend towards the use of plastic sphere inserts as a rational solution for reducing the weight of floor slabs;

confirmed effectiveness of the BubbleDeck technology based on both numerical modeling and laboratory testing results;

existing gaps in the standardization of insert geometry selection, particularly in relation to span length, load type, and concrete grade.

This provides a basis for further research, which should focus on the comparative analysis of slab variants with different insert diameters, optimization of reinforcement, and ensuring compliance with regulatory stiffness requirements.

MAIN RESEARCH

Modern approaches to the design of reinforced concrete slabs increasingly rely on economical solutions for efficient material use and reduction of loads on structural building elements. One of the promising solutions in the construction sector is the BubbleDeck system, which involves the introduction of hollow plastic sphere inserts made from recycled polymer materials into the concrete volume.

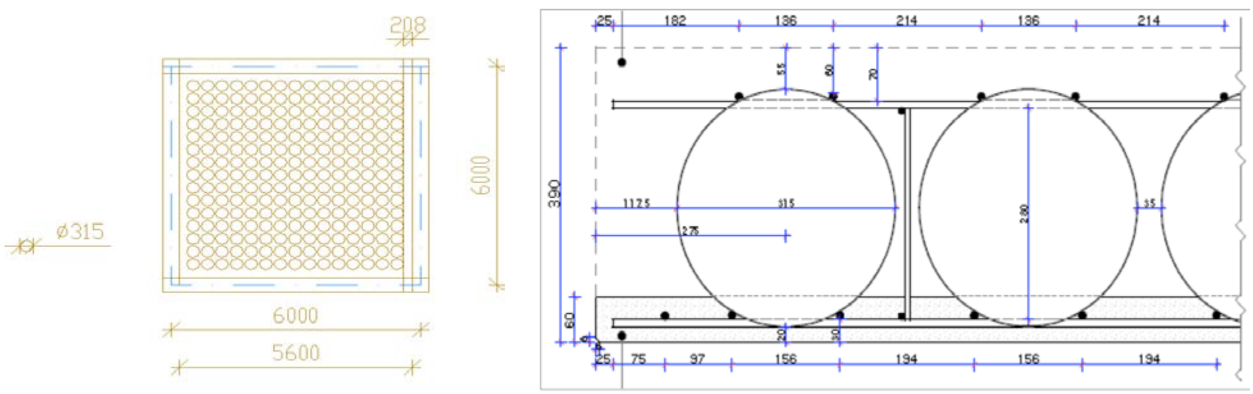
This approach enables a reduction in slab weight without compromising load-bearing capacity by removing concrete from the neutral axis of the cross-section.

The study examined nine design variants of lightweight monolithic floor slabs incorporating plastic sphere inserts. The main objective was to establish the relationship between the diameter of the plastic spheres, panel geometry (spans and slab thickness), load-bearing capacity, and economic efficiency. The research included: numerical modeling using the Lira software package; determination of the stress-strain state of the slabs; analysis of deflections and bending moments; reinforcement design; and comparative evaluation of variants based on techno-economic criteria such as concrete and reinforcement consumption, and the cost per 1 m² of the floor slab.

The study considered slabs with dimensions of 6×6 m, 7×7 m, and 8×8 m, with three varying diameters of plastic sphere inserts—180 mm, 315 mm, and 500 mm. The slab thickness ranged from 230 mm to 600 mm depending on the size of the sphere inserts, which was calculated based on the placement of the inserts between the top and bottom flanges of the floor slab. For all variants, concrete of class C20/25 [18] and reinforcement of classes A400c and Bp-I were used. The slab is supported on all four edges by monolithic beams, ensuring a two-way slab behavior (see Fig. 1).

For each of the nine variants, loads were modeled in accordance with the DBN "Loads and Effects" [19]. The loads included: permanent actions (self-weight of the slab, finishing, thermal insulation); variable loads (service loads for a residential building); and snow loads (as applicable for the city of Dnipro).

Finite element modeling of slabs with sphere inserts [20, 21] enabled the determination of the main performance characteristics of the slabs: bending moment distribution in two directions; maximum deflections; and stress concentration zones (see Fig. 2).



a *b*

Fig.1. Structural diagram of a floor slab with voids made of plastic balls:
a – layout plan of structural elements with an insert ball diameter of 315 mm;
b – section of a floor slab with an insert ball diameter of 315 mm.

Рис.1. Конструктивна схема плити перекриття з порожнечами із пластикових куль:
а – план розташування конструктивних елементів при діаметрі куль-вставок 315 мм,
б – переріз плити перекриття при діаметрі куль-вставок 315 мм.

The slab with sphere inserts of 180 mm diameter and a thickness of 230 mm exhibited a maximum deflection of up to 9.2 mm at a 6 m span, which is within the allowable deflection limit (the limit according to regulatory documents [22] is 24 mm). For the 8×8 m slabs with 500 mm diameter sphere inserts and an overall thickness of 600 mm, deflections reached 15.1 mm, also within permissible limits. However, these cases require increased

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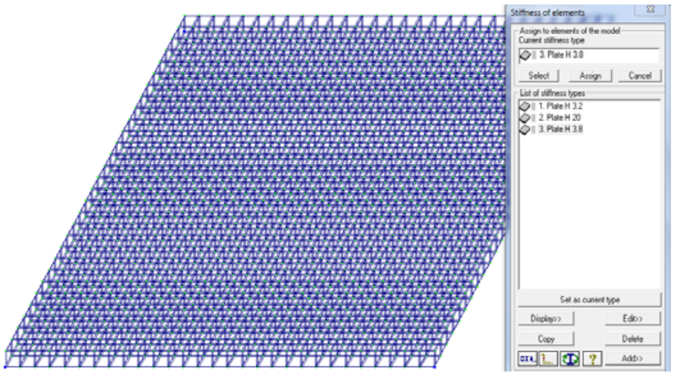
reinforcement in the support zones. Deflections of the slab variants are presented in Table 1.

Figure 3 presents a comparative chart of the maximum bending moments (M_max) for nine variants of lightweight slabs with plastic sphere inserts. As the span length and the diameter of the sphere inserts increase, the load on the slab also increases, which is reflected in the rise of the bending moment values.



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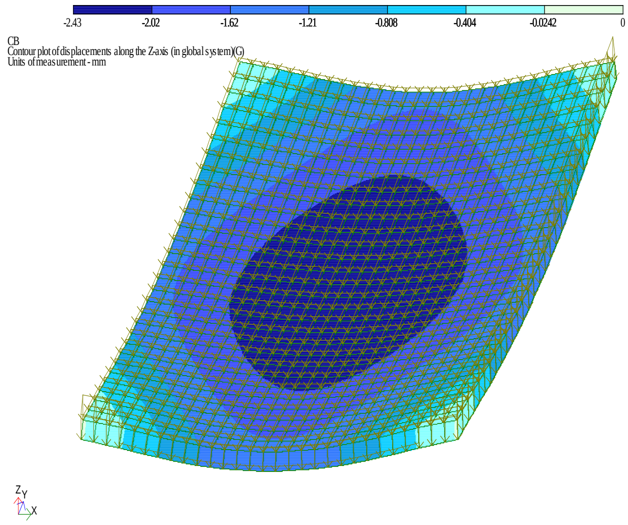

b

Fig.2. Lightweight reinforced concrete floor with plastic-ball void formers:
a – Calculated model with an insert ball diameter of 315 mm;
b – Deformed floor plan with an insert ball diameter of 315 mm.
Рис.2. Полегшене залізобетонне перекриття з порожнечами із пластикових куль:
а – розрахункова схема при діаметрі куль-вставок 315 мм,
б – деформована схема при діаметрі куль-вставок 315 мм.

Table 1. Results of deflection determination in various slab configurations
Табл. 1. Результати визначення прогинів в різних варіантах перекриття

Maximum slab deflections, mm			
Span length, m	Diameter of sphere inserts, mm		
	180	315	500
6	9,2	10,9	12,0
7	10,3	11,2	13,6
8	11,5	13,3	15,1

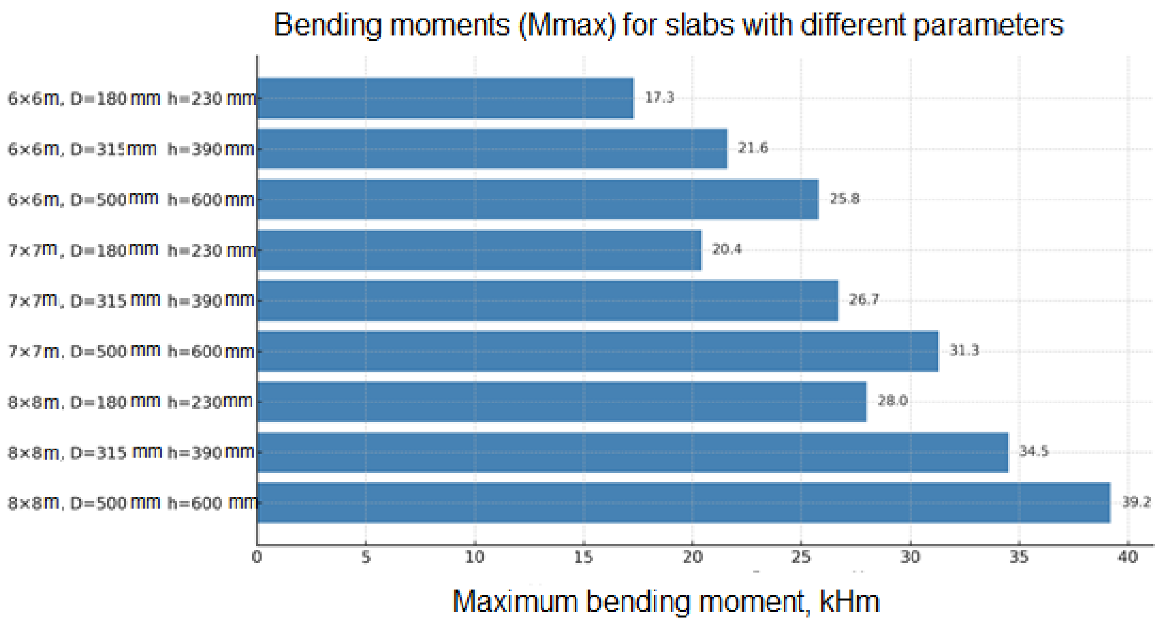

Fig.3. Maximum bending moments in various slab configurations
Рис.3. Максимальні згинальні моменти в різних варіантах плит перекриття

Based on the calculations of concrete consumption per 1 m² of slab with voids in the form of sphere inserts for each variant, it was established that concrete savings can range from 20.9% to 39% compared to a solid monolithic slab of the same thickness (see Table 2). The calculated concrete savings indicate significant potential for material volume reduction when using plastic inserts. As shown in the table, the maximum concrete savings (up to 39%) can be achieved with the use of sphere inserts; however, this requires careful control of deflections and reinforcement [23]..

Table 2. Comparative table of concrete usage for different design options
Табл. 2. Порівняльна таблиця варіантів витрат бетону

№	Slab size, m/	D, mm.	h, mm.	Concrete consumption m³/m²	Solid slab m³/m²	Concrete savings, %
1	6×6	180	230	0.182	0.230	20.9
2	7×7	180	230	0.171	m0.230	25.7
3	8×8	180	230	0.169	0.230	26.5
4	6×6	315	390	0.246	0.390	36.9
5	7×7	315	390	0.238	0.390	39.0
6	8×8	315	390	0.246	0.390	36.9
7	6×6	500	600	0.454	0.600	24.3
8	7×7	500	600	0.439	0.600	26.8
9	8×8	500	600	0.428	0.600	28.7

Reinforcement selection was carried out in accordance with current regulatory documents [24, 25]. The calculation considered both the tensile and compressive zones in the upper and lower parts of the slab. Particular attention was paid to: densification of reinforcement in the support zones; ensuring the protective concrete cover (≥25 mm). The analysis showed that the size and spacing of the reinforcement mesh depend on the location within the slab. In the column zones (support areas), the peak moment concentrations required strengthened reinforcement.

Based on the reinforcement results, the reinforcement consumption for slabs of different variants was calculated. Taking into account the consumption of both concrete and reinforcement for the various slab options, the cost per 1 m² of slabs with sphere inserts was determined.

The cost diagram of the different slab variants is presented in Figure 4.

The diagram shows a comparison of the manufacturing cost per 1 m² of slab variants using plastic sphere inserts with different insert diameters and spans. A trend of increasing cost with larger insert diameters is observed, which is associated with the need to increase slab thickness and the corresponding volume of work.

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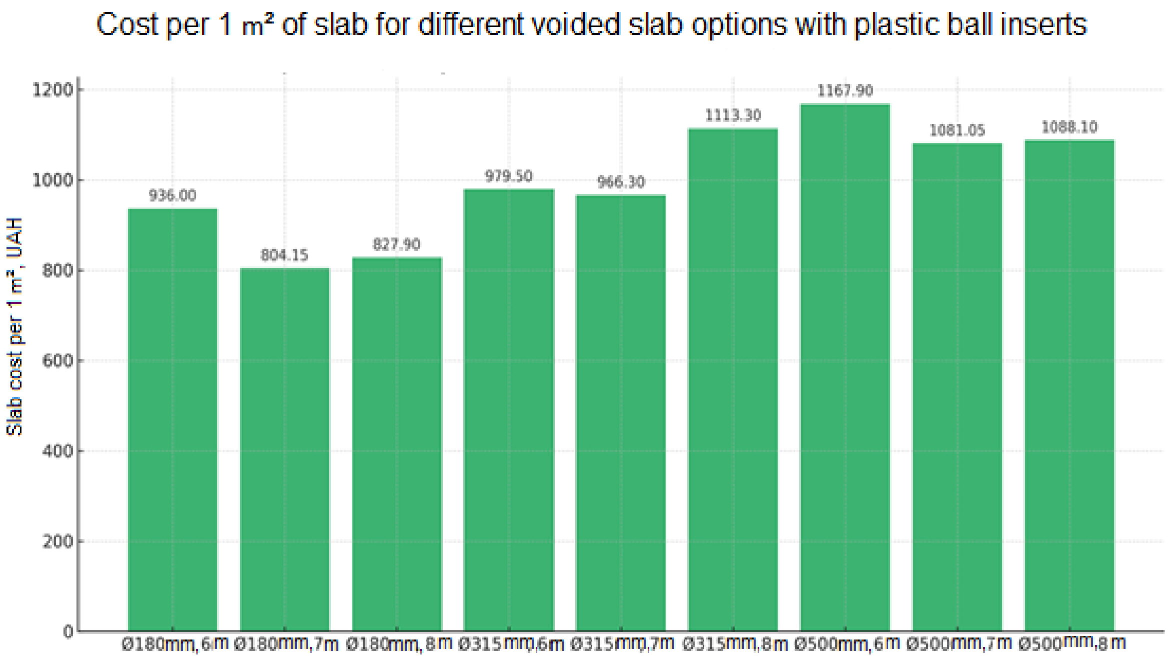

Fig.4. Unit cost per square meter for various BubbleDeck slab options
Рис.4. Вартість 1 м² перекриття для різних варіантів плит перекриття типу BubbleDeck

The slab design using plastic sphere inserts as void formers allows for the use of recycled polyethylene, significantly reducing the environmental impact of construction. Additionally, the lightweight structure:
- decreases transportation costs;
- educes the overall load on the supporting frame elements and foundation structures;
- shortens concreting durations due to smaller concrete volumes.

CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

During this study, a comprehensive analysis was carried out on nine variants of lightweight monolithic slabs incorporating plastic sphere inserts, which involve the use of hollow plastic spheres in the neutral axis of reinforced concrete slabs.

As a result of the conducted study, a clear relationship was established between the geometric parameters of slabs with plastic sphere inserts as void formers (diameter of plastic spheres, slab thickness, span) and their key techno-economic indicators: weight, stiffness, concrete and reinforcement consumption, and overall cost-efficiency metrics.

The numerical modeling conducted demonstrated that this system allows a significant reduction in slab weight (by 20–40%) without critically affecting the stiffness and load-bearing capacity of the structure. It was found that the optimal variant in terms of the “weight–deflection–cost” ratio is the slab with a sphere diameter of 315 mm, a thickness of 390 mm, and a span of 7×7 m.

The obtained results confirm the effectiveness of slabs with plastic sphere inserts for use in multi-storey residential and public buildings, especially under conditions where foundation load limitations apply. The reduction in the slab’s self-weight positively influences the reduction of reinforcement volumes, simplifies installation, lowers transportation costs, and improves the environmental aspect (due to the use of recycled polyethylene).

Prospects for further research include studying the effects of temporary loads (seismic, thermal) on the behavior of slabs with plastic sphere inserts; and assessing the durability and fire resistance of such slabs considering their long-term service life.

Thus, the structural design of slabs using plastic sphere inserts represents a promising approach to the rational design of slab constructions, combining economic efficiency, environmental friendliness, and structural effectiveness.

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ВПЛИВ ГЕОМЕТРИЧНИХ ПАРАМЕТРІВ ПЕРЕКРИТТЯ НА ТЕХНІКО-ЕКОНОМІЧНІ ПОКАЗНИКИ ПОЛЕГШЕНИХ ПЛИТ ПЕРЕКРИТТЯ ТИПУ BUBBLEDECK

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Анотація. У статті надано результати числового дослідження роботи варіантів плит полегшеного монолітного перекриття системи типу BubbleDeck, які виробляють з використанням пластикових порожнистих куль-вставок для вилучення неефективного бетону з нейтральної зони плити. Такий підхід допускає суттєво змен-шити масу конструкції, не знижуючи при цьому її несучу здатність. Метою дослідження було вивчення впливу геометричних параметрів перекриття, зокрема, діаметра пластикових куль, висоти плити та прольоту — на напружено-деформований стан та техніко-економічних показники плити перекриття з використанням вставок із пластикових куль.

Для досягнення мети було створено дев’ять варіантів моделей плит полегшеного перекриття з діаметрами куль 180 мм, 315 мм і 500 мм, які розміщені в плитах розміром 6×6 м, 7×7 м та 8×8 м відповідно. Висота плит змінювалась в залежності від діаметру куль від 230 мм до 600 мм. Усі варіанти було змодельовані в програмному комплексі Ліра. У моделях враховано реальні навантаження, включно з власною вагою, експлуатаційним і сніговим навантаженням.

У результаті аналізу моделей встановлено, що використання пластикових вставок дозволяє зменшити масу плити до 39% у порівнянні з традиційними суцільними перекриттями. При цьому прогини у всіх варіантів не перевищують нормативних меж. Найкращі результати з точки зору загальних техніко-економічних показників отримано для варіанта з діаметром куль 315 мм і прольотом 7×7 м. Для цього типу плити обсяг бетону зменшився на 39%, а витрати арматури — на 10–12%.

У статті також наведено схеми деформацій та порівняльні таблиці характеристик усіх варіантів плит. Зроблено висновки щодо доцільності використання системи типу *BubbleDeck* при проєктуванні будівель цивільного призначення, зокрема в умовах обмеженого навантаження на фундаменти або за необхідності зниження витрат на матеріали та логістику.

Ключові слова: полегшені перекриття; монолітна плита; пластикові кулі; BubbleDeck; числове моделювання.

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