Збірник наукових праць. Галузеве машинобудування, будівництво
Academic journal. Industrial Machine Building, Civil Engineering
http://journals.nupp.edu.ua/znp
https://doi.org/10.26906/znp.2022.58.2858

УДК 624.016.046

Design of modified prefabricated beamless floors for multi-storey residential buildings

Yermolenko Dmytro[1], Nyzhnyk Oleksandr[2], Tehza Ivan[3], Yefimenko Olena[4]

[1] National University «Yuri Kondratyuk Poltava Polytechnic» https://orcid.org/0000-0001-6690-238X
[2] O.M. Beketov National University of Urban Economy in Kharkiv https://orcid.org/0000-0002-2672-1987
[3] «Budmaterial standard-control» LLC (Kremenchuk) https://orcid.org/0000-0001-7729-4615
[4] MITIT (Poltava) https://orcid.org/0000-0001-5949-623X
*Corresponding author E-mail: bimbud2018@gmail.com

The article presents an example of the implementation of the structures of the prefabricated beamless floor system using modified reinforced concrete slabs for a multi-story residential building. A comparative analysis of the effectiveness of the proposed prefabricated beamless floor using modified round hollow slabs with a monolithic reinforced concrete floor was performed. The results of the evaluation of the technical and economic efficiency of the presented floor indicate its competitiveness comparing with traditional structures

Key words: beamless floor, residential building, reinforced concrete.

Проектування модифікованих збірних безбалкових перекриттів для багатоповерхових житлових будинків

Єрмоленко Д.А.[1], Нижник О.В.[2], Тегза І.І.[3], Єфіменко О.І.[4]

[1] Національний університет «Полтавська політехніка імені Юрія Кондратюка»
[2] Харківський національний університет міського господарства ім. О.М.Бекетова
[3] ТОВ «Будматеріал стандарт-контроль», м. Кременчук
[4] ВКСС ВІТІ, м. Полтава
*Адреса для листування E-mail: bimbud2017@gmail.com

У статті розглянуто приклад впровадження конструкцій системи модифікованого збірного безбалкового перекриття для багатоповерхового житлового будинку у м. Кременчук. У якості модифікованого збірного каркасу будівель запропоновано варіант з поєднанням збірних круглопустотних плит, їх модифікацій. Проект багатоповерхового житлового будинку відповідає обраному типу й стандарту по всім характерним його показникам. Запроектовано три типи плит: надколонна; міжколонна; пролітна. Виконане чисельне моделювання роботи окремих плит збірного безбалкового перекриття. Це дало можливість оцифрувати за результатами розрахунку напружено-деформований стан об'єкта, виконати детальний аналіз отриманих даних за полями переміщень та напружень, за епюрами зусиль та прогинів, за мозаїками руйнування елементів тощо. З метою отримання експериментальних результатів, були випробувані міжколонні залізобетонні круглопустотні плити натурних розмірів у заводських умовах. Результати експерименту засвідчили про те, що запропоновані залізобетонні міжколонні круглопустотні плити надійні в роботі та можуть бути використані в складі збірного безбалкового перекриття. За результатами проектування був виконаний порівняльний аналіз ефективності запропонованого збірного безбалкового перекриття із використанням модифікованих круглопустотних плит із монолітним залізобетонним перекриттям. Приведені витрати на влаштування даної системи перекриття на 27 % менші за витрати на монолітні залізобетонні перекриття. Результати оцінювання техніко-економічної ефективності представленого перекриття свідчать про конкурентоздатність у порівнянні з традиційними конструкціями.

Ключові слова: безбалкове перекриття, житловий будинок, залізобетон.

Introduction

The practice, methodology, amount of housing design and construction correspond to the social and economic transformations taking place in Ukraine. At the current stage of development, the role of the architectural and building complex in ensuring the convenience of the living environment of man and society is growing.

Along with this, taking into account the consequences of the enemy's full-scale invasion of the territory of Ukraine, which caused catastrophic destruction in cities and villages and provoked an unprecedented housing crisis for many Ukrainians, a global task appeared - the post-war reconstruction of the sphere of housing construction by increasing the volume of construction of affordable housing. This task can be accomplished with the help of innovative technologies in constructing with the use of effective constructive solutions for the restoration of existing and new construction of residential buildings. The use of modern structural schemes (frame and frame-monolithic) in residential construction due to the increase in the step of the carrying structures makes it possible to create a flexible layout of apartments with the possibility of changing it over time. One of the options for solving these problems is the construction of buildings with prefabricated beamless floors.

Such structural systems provide free planning solutions that can be transformed at the request of the consumer at any stage of design, construction and operation. They also allow to give individual architectural expressiveness, which eliminates the monotony of territorial development.

Review of the research sources and publications

In recent decades, intensive construction has already been carried out according to original individual projects, in which significant deviations from the typical schemes for the use of structural elements are allowed. Modern construction technologies based on beamless structures represent the greatest space for architectural fantasies [1, 3, 4, 10]. With the use of modern prefabricated beamless floors, it is possible to build objects of various purposes: residential buildings, public and administrative buildings, as well as special objects. The introduction and use of beamless floors shapes the course of development of mass construction both in Ukraine and abroad. Such overlaps provide the possibility of construction of buildings of any configuration in plan with various spatial and planning solutions, and also leads to a decrease in labor costs, capital investments and steel costs. Numerous studies of domestic and foreign scientists [3, 4, 6-11] have established that when using prefabricated beamless floors, compared to conventional ones, the structural height of the floor is reduced, which leads to a decrease in the total height of buildings and saves cubic capacity by 10-12%. Costs of wall materials are reduced, and when operating buildings – costs of energy carriers are reduced.

At the same time, the use of composite steel-concrete structural elements is one of the possible ways of industrialization, increasing of labor productivity, reduction of terms and cost of construction of beamless floors [1, 2, 5].

Definition of unsolved aspects of the problem

A further step in the modification of prefabricated frames of buildings and structures is a possible option with a combination of prefabricated circular hollow plates, their modifications and a composite steel-concrete beamless frame. The tasks aimed at finding rational parameters of such structures, researching their strength and deformability and implementing the results in construction are expedient and relevant.

Problem statement

The purpose of the article is to reveal key perspectives and the possibility of using modified prefabricated beamless floors for multi-story residential buildings.

Basic material and results

In view of the above, on the basis of numerous experimental and theoretical studies, the team of authors proposed a design of the carrying frame of a multi-story residential building in the city of Kremenchuk using a prefabricated beamless floor system. At the same time, the condition of compliance of the project of a multi-story building with the chosen type and standard in terms of all its characteristic indicators was set. The planning organization of apartments should ensure convenient functional connections between individual rooms, create comfortable conditions for living and meet the requirements of [12-14].

The design object has a structural scheme with longitudinal carrying walls. The walls are made of solid brick. To ensure the requirements of effective resistance to heat transfer, a hinged insulation system using effective insulating materials is attached to the outer surface of the enclosing structures. The floor is made of typical round hollow slabs.

A multi-storey residential building consists of three typical sections. Structural scheme of a separate frame-type section (Fig. 1). Typical reinforced concrete columns with a square section of 400×400 mm are used as racks. The step between the longitudinal axes is 6.9 m. The planning of the premises requires a different step between the transverse axes (Fig. 2), it ranges from 3.6 to 6.0 m. A column grid of 6.0×6.9 m was adopted for the design of the slabs of the beamless floor. The slabs above the columns have geometric dimensions in plan of 1.2×1.2 m and are axially attached to the longitudinal and transverse axes (Fig. 3).

Inter-column slabs are 1.2×4.8 m in plan and are located in the longitudinal direction with zero anchoring. The filling slabs are made in the form of modified multi-hollow plates, which are located parallel to the transverse axes.

The floor is affected by: payload (200 kg/m^3); floor structures (screed, sound insulation); own weight of slabs of the floor system.

Three types of slabs are designed: columnar; intercolumnar; flying (Figs. 4-6). Each type of slabs is designed as the most loaded option.

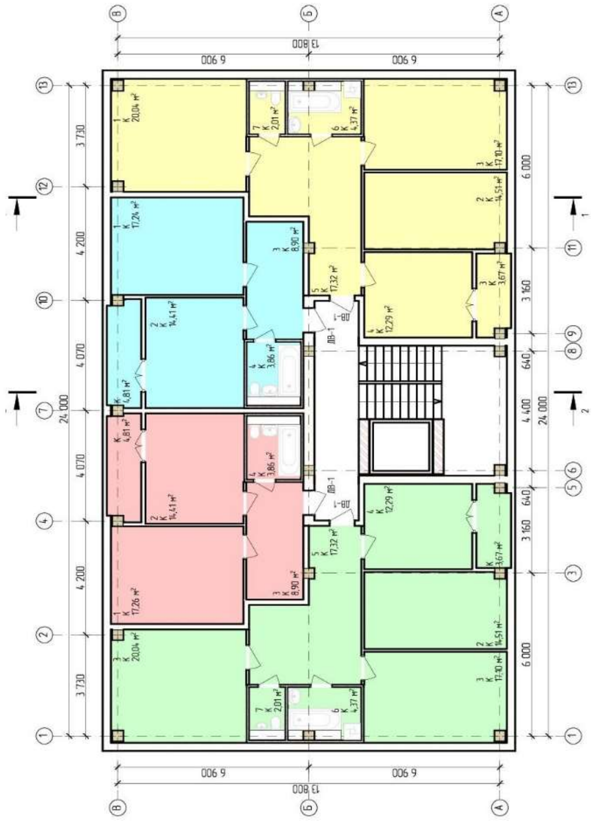

Figure 1 – Plan of a typical floor of an ordinary section of a residential building

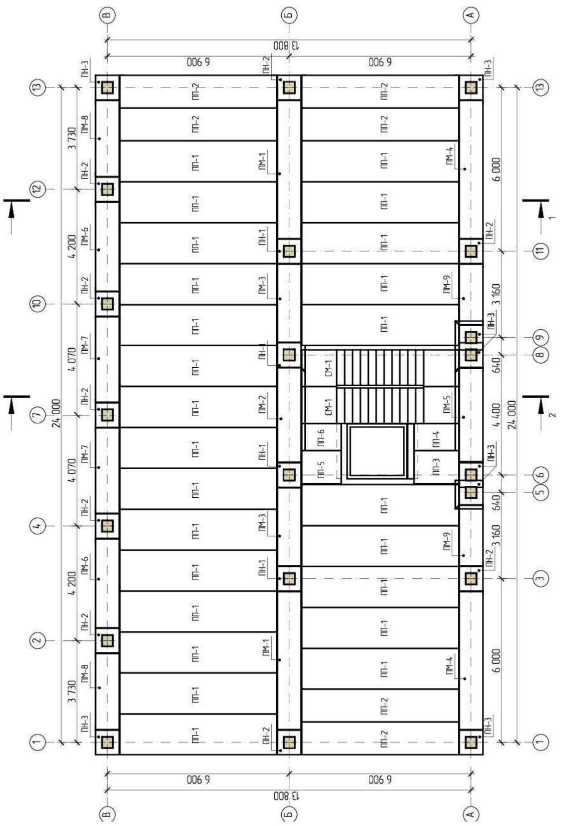

Figure 2 – Layout of slabs of the proposed version of the beamless floor

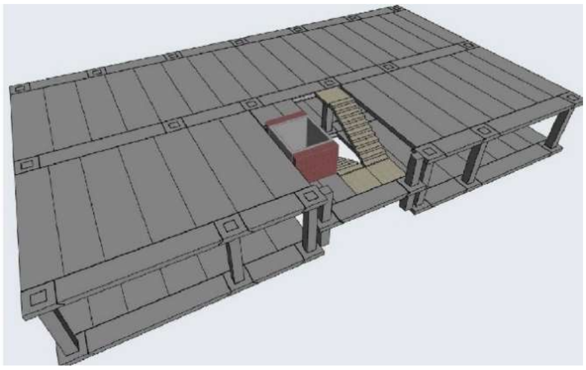

Figure 3 – System using reinforced concrete beamless floor with modified round hollow slabs

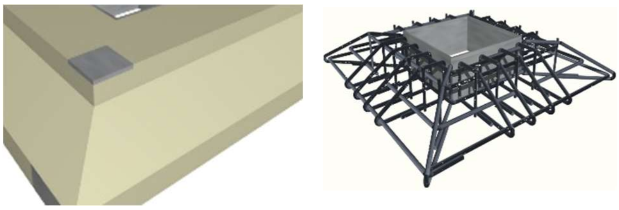

Figure 4 – Columnar slab

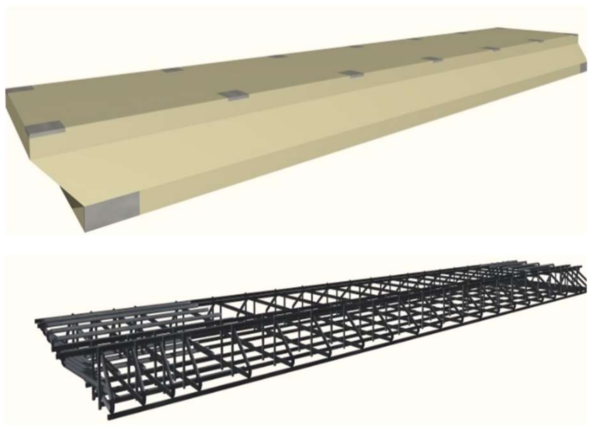

Figure 5 - Intercolumnar slab

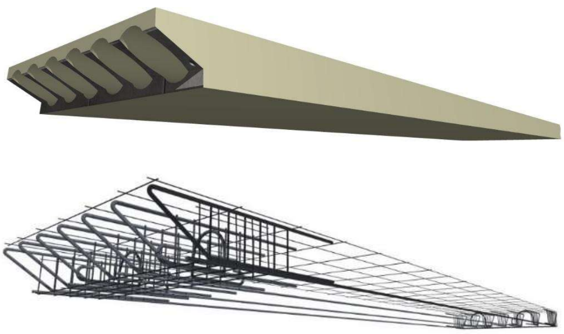

Figure 6 – Flight slab

The span slab is loaded with its own weight, the weight of the floor structure and the payload. All this load is reduced to 1 m^2. The length of the round hollow slab is 5.7 m. The intercolumnar slab has dimensions of 4.8×1.2 m, the above columnar - 1.2×1.2 m.

Numerical modeling of individual slabs of a prefabricated beamless floor was performed with the help of the "LIRA-SAPR" PC software complex. This made it possible to digitize the stress-strain state of the object based on the calculation results, to perform a detailed analysis of the received data according to displacement and stress fields, force and deflection diagrams, element destruction mosaics, etc. The calculation using the LIRA-SAPR PC was performed on the basis of the developed finite element models. At each stage, the correctness of the specified output data is checked by means of the software complex. Based on the results of the calculation, all components of the stress-strain state are calculated in certain points of the models (Figs. 7-8).

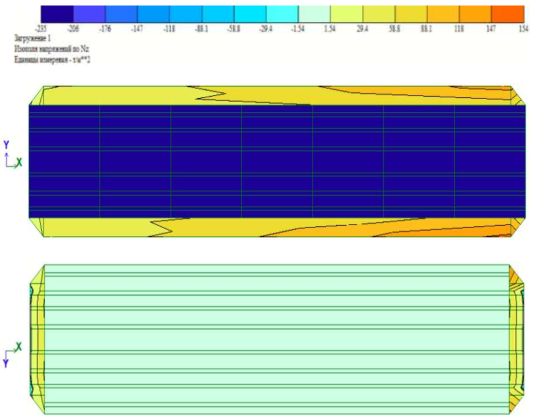

Figure 7 – General stress state of the intercolumnar slab (normal stresses σ_x):
а – upper edge; *б* – is the lower edge

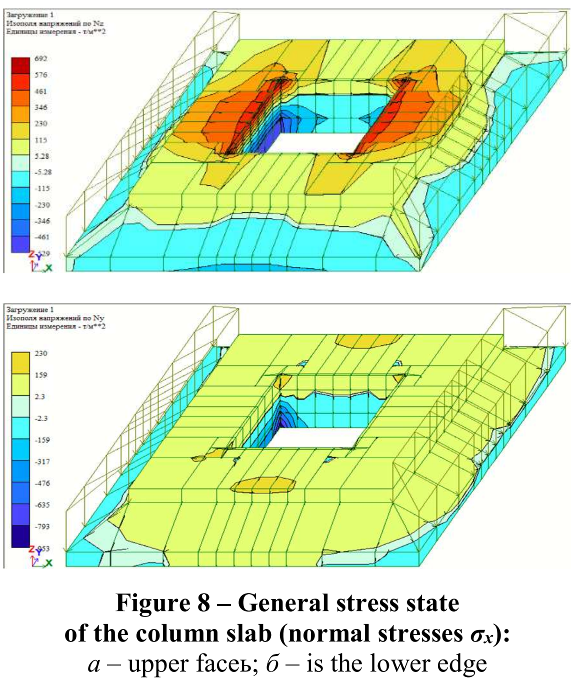

Figure 8 – General stress state of the column slab (normal stresses σ_x):
а – upper facеь; *б* – is the lower edge

According to the results of the calculations, working drawings of the load-bearing structures of the beamless floor were developed, which are given in [5].

In order to obtain experimental results, inter-column reinforced concrete round hollow slabs of full size were tested in factory conditions (Figs. 9-10). It gives the possibility to investigate the peculiarities of the operation of reinforced concrete slabs as part of a prefabricated beamless floor.

Figure 9 – General view of the test slab on the test bench

Figure 10 – Test sample of inter-column slab during testing

The test was carried out under short-term loads. According to the results of laboratory tests of reference samples of cubes and prisms, the mechanical characteristics of concrete were obtained. Determination of physical and mechanical properties of steel was carried out by testing 3 standard longitudinal samples in the form of rods.

The stresses that corresponded to the yield strength and temporary resistance of the material were determined by the σ – ε diagram. The average value of the defective minimum of the tested samples was taken as the resistance of the steel pipe σ_u and σ_y. Physical and mechanical characteristics are equal to σ_y = 800 МПа, σ_u= 1050 МПа. The modulus of elasticity of steel was determined according to the diagram, E_s = 2,1×10^5 МПа.

The analysis of the results of experimental studies is based on the obtained indicators of the used devices, as well as visual observation of the behavior of the structure during the test.

As a result of experimental studies, the actual stress-strain state was established and the bearing capacity of inter-column reinforced concrete slabs, which is part of the beamless floor, was determined [5].

Thus, it was noted that a significant increase in strain in the stretched zone is duplicated by the same increase in strains in the compressed zone. At this moment, the total external force was 163 kN. The carrying capacity of the intercolumnar slabs with prestressing was 258.6 kN. The plate structure did not collapse during the experiments, but the relative deflection exceeded the limit value of 1/200. At the same time, the theoretical carrying capacity of the intercolumnar slab with prestressing was 211.1 kN. The difference was 21.3%. It can be stated that the theoretical carrying capacity, which is calculated according to the normative methodology, allows to establish the carrying capacity of such slabs with sufficient accuracy. It was also established that the longitudinal compressive starins of the upper compressed fiber in the limit state are understressed by 8%, and the strains of the lower stretched fiber exceed the ultimate tensile strains of concrete by 35%. Experimental deflections almost coincided with their theoretical values.

The results of the experiment proved that the proposed reinforced concrete intercolumnar round hollow slabs are reliable in operation and can be used as part of a prefabricated beamless floor.

Based on the results of the design, a comparative analysis of the effectiveness of the proposed prefabricated beamless floor using modified round hollow slabs with a monolithic reinforced concrete floor was performed. This analysis was performed on the basis of the cost of structures and materials provided by the "Svitlovodsky Plant of Reinforced Concrete Products" and the Private Enterprise "Construction Firm "Karyatida".

For comparison, the above-suggested version of the layout of the elements of the prefabricated beamless floor with the designed required number of structures was used. The total cost of the prefabricated beamless ceiling was calculated separately and the combined cost of 1 m2 of the ceiling was calculated.

The consumption of reinforcement per 1 m3 of concrete for a monolithic floor is assumed to be 150 kg, using the averaged indicators of similar objects.

After calculating the cost of 1 m2 of the proposed beamless floor using modified multi-hollow slabs and a monolithic reinforced concrete floor with a thickness of 160 and 180 mm, the cost of such floors was compared and it was determined which of them is the most cost-effective and to what extent compared to the others. Calculation data are presented in Table 1.

Table 1 – Comparative table of technical and economic indicators of the proposed beamless floor system and monolithic reinforced concrete floor with a thickness of 160 mm and 180 mm

Cost	Monolithic reinforced concrete floor thickness		Prefabricated beamless floor	Excess in % between beamless and monolithic, thickness	
	160 mm	180 mm		160 mm	180 mm
Materials, structures of factory production, UAH	634,88	714,24	797,99	25,7	11,7
Works, UAH	384	432	43,62	-88,6	-89,9
1м^2 ready floor	1018,88	1146,24	841,61	-17,4	-26,6
% materials/structures from the total cost 1м^2 ready floor	62,31	62,31	94,82	–	–
% works from the total cost 1 м^2 ready floor	38,69	37,69	5,18	–	–

From the table, we can see that the cost of prefabricated beamless floor structures is greater than the cost of monolithic floor materials both 160 mm thick and 180 mm thick by 25.7 and 11.7 percent, respectively. This is understandable, because the cost of the construction of a prefabricated beamless floor is indicated as for a finished product manufactured in factory conditions. The cost of work in the execution of a monolithic reinforced concrete floor is significantly higher compared to a prefabricated beamless one by 88.6 and 89.9 percent for a floor with a thickness of 160 and 180 mm, respectively. This is also understandable, because with monolithic concreting, all formwork and monolithic work is performed on the construction site, and with prefabricated beamless flooring, ready-made structures are delivered to the site.

Comparing the percentage ratio of the cost of work performed on the construction site and the cost of materials or structures delivered from the factory, we obtained the following result: with monolithic concreting, the percentage of the cost of work in the finished structure was 37.69, and with prefabricated beamless flooring - only 5.18. The total cost of 1 m2 of a monolithic floor compared to a beamless prefabricated one is higher by 17.4 and 26.6% for a monolithic floor with a thickness of 160 and 180 mm, respectively.

In order to understand why a significant economic effect is obtained when performing a prefabricated beamless floor, a comparison of the consumption of materials for the considered floor systems was performed. Since the comparison is made for the previously proposed planning solution, where different elements of a prefabricated beamless floor and a monolithic floor are used, we calculate the total cost of materials for a prefabricated beamless floor and the total cost of works, and thus the total cost of 1 m2 of the floor is calculated. Table 2 shows that the given thickness of the beamless prefabricated floor is 182 mm, compared to the monolithic reinforced concrete floor with a thickness of 160 and 180 mm, the consumption of concrete will be greater by 13.75 and 1.11 percent, respectively, and the consumption of reinforcement will be less by 0.32 and 11.4 percent. However, the extremely high cost in the monolithic floor is occupied by the work, which is greater than when installing a prefabricated beamless floor by 88.6 and 89.9%, respectively. Thus, it can be concluded that the main component of the economic efficiency of the presented prefabricated beamless floor compared to the monolithic one is the cost of the work.

It should be noted that the prefabricated beamless floor presented in this work was designed in axial dimensions from 3.16 to 6 m along the numerical axes and 6.9 m along the letter axes, respectively, the inter-columnar slabs had different lengths. However, the given cost of 1 m of inter-column slab was taken for the maximum slab length of 5.1 m. Taking into account this fact, it can be concluded that in slabs of shorter length, there will be a smaller number of working fittings, accordingly, the economic effect will be even greater.

Also, an additional economic effect can be obtained by optimizing the reinforcement of the column slab, since in this version it is very expensive and extremely over-reinforced – about 518 kg of reinforcement per 1 m^3.

Based on the previous results, it can be concluded that the maximum economic effect of the presented prefabricated beamless floor using modified round hollow slabs can be obtained with the maximum axial dimensions of 6 m along the digital axes, using the maximum long inter-column slabs of the series with a length of 5.1 m, and maximum axial dimensions along letter axes - 6.9 m, for the use of modified multi-hollow slabs with a length of 6 m.

Table 2 – Material consumption per 1 m2 of finished floor

Material, work	Monolithic reinforced concrete floor thickness		Prefabricated beamless floor	Excess in % between beamless and monolithic, thickness	
	160 mm	180 mm		160 mm	180 mm
Concrete, $м^3$	0,16	0,18	0,182	13,75	1,11
Steel, kg	24,00	27,00	23,92	-0,32	-11,40
Work, UAH	384,00	432,00	43,62	-88,64	-89,90

Conclusions

The proposed prefabricated reinforced concrete beamless ceiling for a multi-story residential building using modified round hollow slabs reduces the costs of installing enclosing structures, foundations and other structural elements. There is also an opportunity to reduce the construction time of the building as a whole. The listed costs for installing this floor system are 27% lower than the costs for monolithic reinforced concrete floors. Therefore, modified prefabricated beamless ceilings are competitive in comparison with traditional structures and can be effectively used in the construction of multi-story residential buildings.

References

1. Лапенко О.І. (2009). *Залізобетонні конструкції з робочим армуванням незнімною опалубкою*. Полтава, АСМІ

2. Онищенко О.Г., Пічугін С.Ф., Онищенко В.О., Стороженко Л.І., Семко О.В., Слюсаренко Ю.С., Ємельянова І.А., Ландар О.М. (2010). *Високоефективні технології та комплексні конструкції в промисловому й цивільному будівництві*. Полтава: ПФ «Форміка», 2010

3. Стороженко Л.І., Єрмоленко Д.А., Нижник О.В., Богоста В.І., Тегза І.І. (2014). Нові ефективні рішення безбалкових збірних перекриттів багатоповерхових будівель. *Галузеве машинобудування, будівництво*, 3(42)-1, 183-187

4. Стороженко Л.І., Нижник О.В., Мурза С.О., Тегза І.І. (2015). Збірне безбалкове перекриття з використанням модифікованих кругло пустотних плит. *Будівництво, матеріалознавство, машинобудування*, 69, 231-236

5. Тегза І.І. (2020). *Збірне безбалкове залізобетонне перекриття з використанням модифікованих кругло-пустотних плит* (Дис. канд. техн. наук.). Полтавська політехніка імені Юрія Кондратюка, Полтава

1. Lapenko A. (2009). *Reinforced concrete structures with working reinforcement fixed formwork*. Poltava: ACMI

2. Onishchenko O.G., Pichugin S.F., Onishchenko V.O., Storozhenko L.I., Semko O.V., Slyusarenko Yu.S., Yemelyanova I.A., Landar O.M. (2010). *Highly efficient technologies and complex designs in industrial and civil construction*. Poltava: PH “Formika”

3. Storozhenko L.I., Yermolenko D.A., Nyzhnyk O.V., Bogosta V.I., Tegza I.I. (2014). New effective solutions for beamless prefabricated floors of multi-story buildings *Industrial Machine Building, Civil Engineering*, 3(42)-1, 183-187

4. Storozhenko L.I., Nyzhnyk O.V., Murza S.O., Tegza I.I. (2015). Precast beamless floor using modified circular hollow plates. *Construction, materials science, mechanical engineering*, 69, 231-236

5. Tegza I.I. (2020). *Precast beamless reinforced concrete floor using modified round hollow plates* (Dis. ... candidate technical of science). National University «Yuri Kondratyuk Poltava Polytechnic», Poltava

6. Epaarachchi D.C, Stewart M.G., Rosowsky D.V. (2002). Structural Reliability of Multistory Buildings during Construction. *Journal of Structural Engineering*, 128, 205-213

7. Johnson R.P. (2004). *Composite Structures of Steel and Concrete: Beams, Slabs, Columns, and Frames for Buildings*. Wiley-Blackwell

8. Häußler-Combe U. (2008). Zur Theorie der Stabwerkmodelle im Stahlbetonbau. *Bauingenieur,* 83, 186-197

9. Muttoni A. (2008). Punching Shear Strength of Reinforced Concrete Slabs without Transverse Reinforcement. *ACI Structural Journal*, Technical Paper July-August, 440-450

10. Silva R.J., Regan P.E. (2005). Punching resistance of unbonded post-tensioned slabs by decompression methods. *Structura Concrete*, 1, 9-21

11. ДБН В.2.2-15:2019 (2019). *Житлові будинки. основні положення*. Київ: Міністерство регіонального розвитку, будівництва та житлово-комунального господарства України

12. Fraqiacomo M., Amadio C, Macorini L. (2004). Model for Collapse and Long-Term Analysis of SteelConcrete Composite Beams. *Journal of Structural Engineering*, 3, 489-497

13. Johnson R.P. (2004). *Composite Structures of Steel and Concrete: Beams, Slabs, Columns, and Frames for Buildings*. Wiley-Blackwell

14. Leon R.T., Rassati G.A., Perea T. (2011). *Composite Construction in Steel and Concrete VI*. American Society of Civil Engineers

6. Epaarachchi D.C, Stewart M.G., Rosowsky D.V. (2002). Structural Reliability of Multistory Buildings during Construction. *Journal of Structural Engineering*, 128, 205-213

7. Johnson R.P. (2004). *Composite Structures of Steel and Concrete: Beams, Slabs, Columns, and Frames for Buildings.* Wiley-Blackwell

8. Häußler-Combe U. (2008). Zur Theorie der Stabwerkmodelle im Stahlbetonbau. *Bauingenieur,* 83, 186-197

9. Muttoni A. (2008). Punching Shear Strength of Reinforced Concrete Slabs without Transverse Reinforcement. *ACI Structural Journal*, Technical Paper July-August, 440-450

10. Silva R.J., Regan P.E. (2005). Punching resistance of unbonded post-tensioned slabs by decompression methods. *Structura Concrete*, 1, 9-21

11. DBN V.2.2-15:2019 (2019). *Residential buildings. substantive provisions*. Kyiv: Ministry of Regional Development, Construction and Housing and Communal Services of Ukraine

12. Fraqiacomo M., Amadio C, Macorini L. (2004). Model for Collapse and Long-Term Analysis of SteelConcrete Composite Beams. *Journal of Structural Engineering*, 3, 489-497

13. Johnson R.P. (2004). *Composite Structures of Steel and Concrete: Beams, Slabs, Columns, and Frames for Buildings*. Wiley-Blackwell

14. Leon R.T., Rassati G.A., Perea T. (2011). *Composite Construction in Steel and Concrete VI*. American Society of Civil Engineers