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STRENGTHENING OF REINFORCED CONCRETE SLABS BY ADDING MONOLITHIC BEAMS: METHODS AND IMPLEMENTATION

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The article examines the problem of strengthening reinforced concrete floor slabs with insufficient load-bearing capacity during reconstruction or increased loads. A method is proposed involving partial integration of additional monolithic reinforced concrete beams through pre-formed openings in the slab. Various approaches are analyzed to ensure composite action between the slab and beams. The study aims to theoretically and experimentally determine slab deflection and develop optimal implementation methods. Preliminary calculations of reinforcement and dowel parameters are provided. Numerical modeling using the LIRA-SAPR software confirms the effectiveness of the solution. Drawings of test specimens are also included. Results show that the added beams reduce slab deflection and improve strength and stiffness, but cause a complex stress-strain state requiring thorough evaluation before application.

Keywords: slabs, strengthening, deflection, reconstruction, strength, LIRA-SAPR.

Introduction

Reinforced concrete floor slabs play a critical role in the structural integrity of buildings. They serve as stiffness diaphragms, distributing horizontal forces and bearing substantial operational and environmental loads. However, over time, their load-bearing capacity may deteriorate due to various factors, including prolonged use, exposure to aggressive chemical or moisture-rich environments, or alterations in the functional purpose of the building. These factors make it necessary to implement targeted strengthening measures to ensure continued safety and performance.

Numerous studies have focused on improving the flexural and shear performance of reinforced concrete (RC) slabs through various strengthening methods, including externally bonded fiber-reinforced polymer (FRP) systems, concrete overlays, and steel or RC jacketing. For example, Gupta and Kumar (2019) demonstrated that RC overlays significantly enhance fatigue resistance and stiffness recovery in deteriorated slabs, while Sobol et al. (2021) analyzed the structural behavior of strengthened RC elements under flexure. Hani and Munir (2020) emphasized the efficiency of embedded concrete beams for improving stiffness and reducing deflections, and Čereš and Gajdošová (2021) reported that additional concrete layers can increase punching shear capacity.

Among these methods, the integration of monolithic reinforced concrete beams directly into existing slabs has emerged as an effective and practical solution for enhancing overall rigidity and load-bearing capacity. This approach ensures composite action between the original and newly added structural components, providing substantial strength improvement without requiring complete slab replacement. Recent investigations confirm that such beam–slab systems achieve improved performance under static and cyclic loads (Fernandes, 2019; Vytak & Bobalo, 2024; Blikharskyy et al., 2017).

The success of this strengthening technique largely depends on several critical parameters – the bond between old and new concrete, the arrangement of reinforcement, and accurate modeling of load redistribution. If these factors are inadequately addressed, stress concentrations and premature cracking may occur, reducing the system's overall reliability.

Therefore, continued research aimed at refining connection design, optimizing beam geometry, and validating the performance of beam-enhanced slabs through numerical modeling is of paramount importance. These efforts contribute directly to enhancing the reliability, service life, and sustainability of strengthened reinforced concrete floor systems.

Materials and methods

Mechanical and physical properties of concrete class C25/30 and reinforcing steel B500B used in this study are presented in Table 1 and Table 2, respectively. All values are provided in accordance with European standard EN 1992-1-1:2004 and national standards DSTU B V.2.6-156:2010 and DSTU 3760:2019.

Table 1

Mechanical and physical properties of concrete C25/30

Class	Cube compressive strength (*fck*,cube), MPa	Cylinder compressive strength (*fck*), MPa	Design compressive strength (*fcd*), MPa	Design tensile strength (*fctd*), MPa	Modulus of elasticity (*E*), GPa	Ultimate strain (ε*cu*), ‰	Partial safety factor (γc)
C25/30	30	25	16.7	~1.57	~30	3.5	1.5

Table 2

Mechanical and physical properties of reinforcing steel B500B

Class	Yield strength (*fyk*), MPa	Design strength (*fyd*), MPa	Tensile strength (*ftk*), MPa	Modulus of elasticity (*E*), GPa	Ultimate strain (ε*uk*), ‰	Partial safety factor (γ*s*)
B500B	500	435	≥ 550	~200	≥ 2.5	1.15

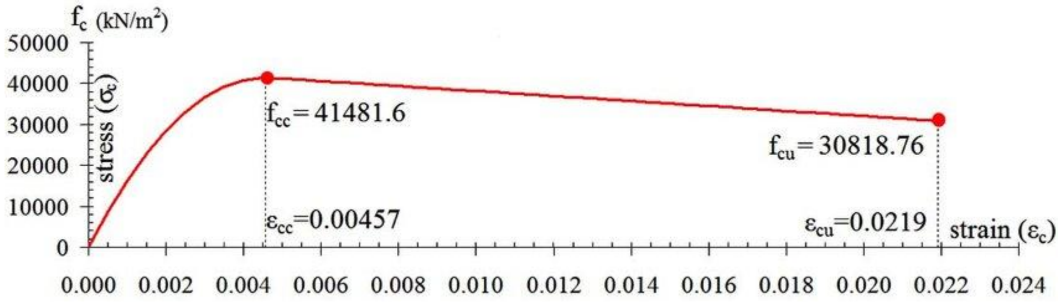

Fig. 1. Stress-strain (σ–ε) diagram for confined concrete core (C25/30 & B550B) according to EN 1998-3

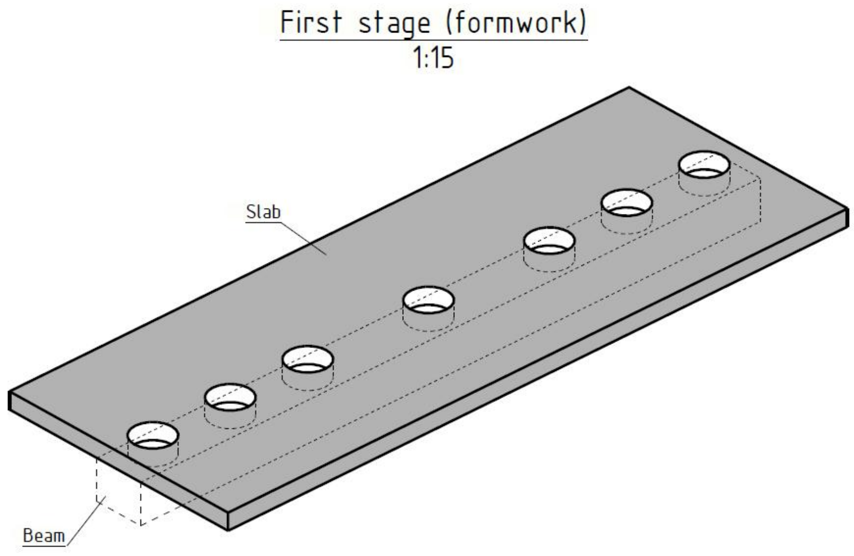

Fig. 2. 3D image of the studied specimen

To evaluate the effectiveness of slab strengthening using integrated monolithic beams, both laboratory and numerical studies are planned. The tested specimens (Fig. 2) have the following dimensions (Fig. 3): thickness – 50 mm, width – 750 mm, length – 2000 mm, and are reinforced with Ø6–8 mm A500C steel bars (Fig. 4).

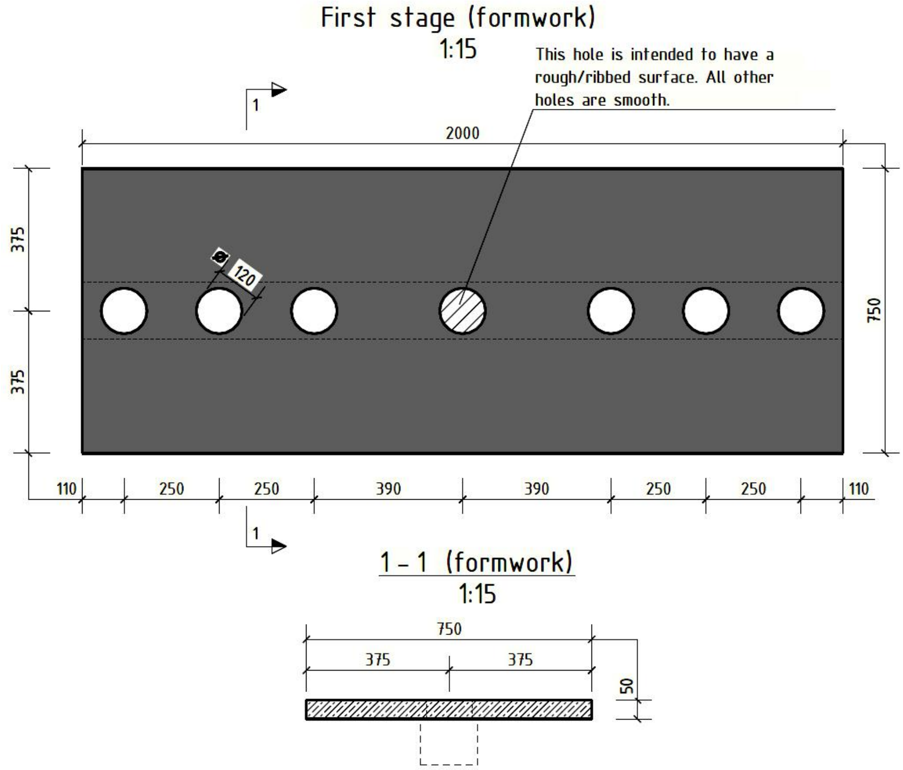

Fig. 3. Formwork drawing of the investigated slab

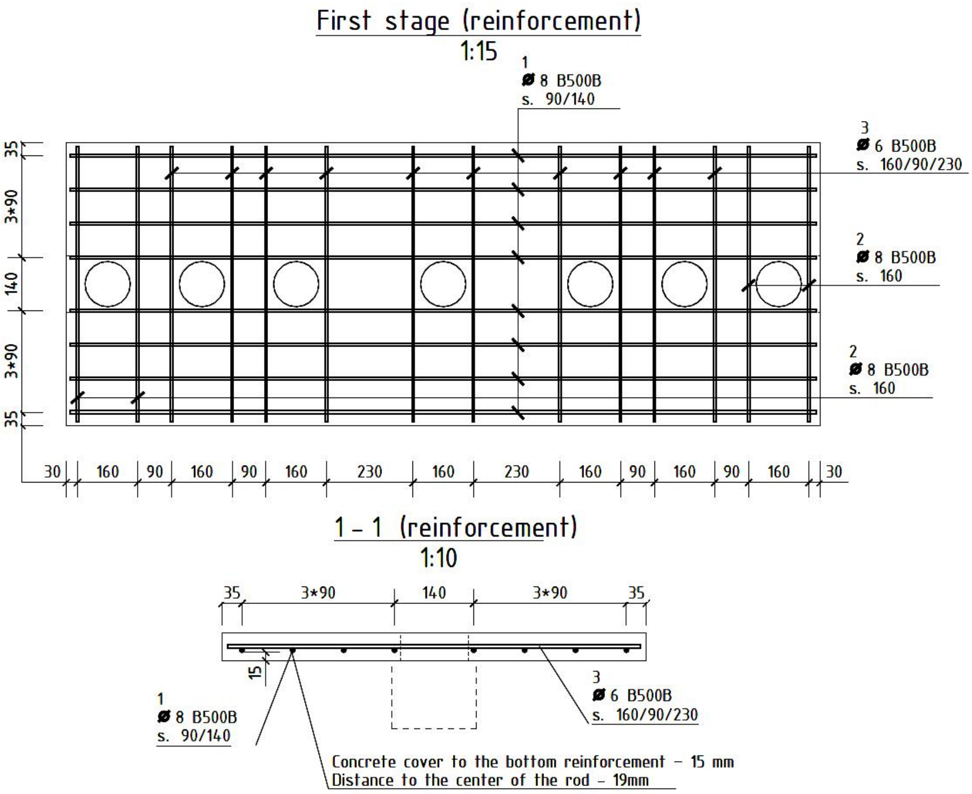

Fig. 4. Reinforcement of the investigated slab

During the preparation stage of the specimens, pre-formed openings with a diameter of 120 mm (dowels) are planned in the slabs, which will subsequently ensure the transfer of shear forces and the maximum possible composite action between the strengthened slab and the beam in this reinforcement method.

At the second stage (Fig. 5), formwork for the beam (Fig. 6) with a reinforcement cage (Fig. 7) is installed under the tested slab, allowing the formation of a monolithic beam. From a visual-aesthetic perspective (to preserve the useful height of the room after strengthening in real conditions), the minimum height of the strengthening beam was set according to calculations – 120 mm; width – 150 mm. During concrete pouring into the openings, metal inserts (Fig. 8) (I-beams or channels) will be installed, which:

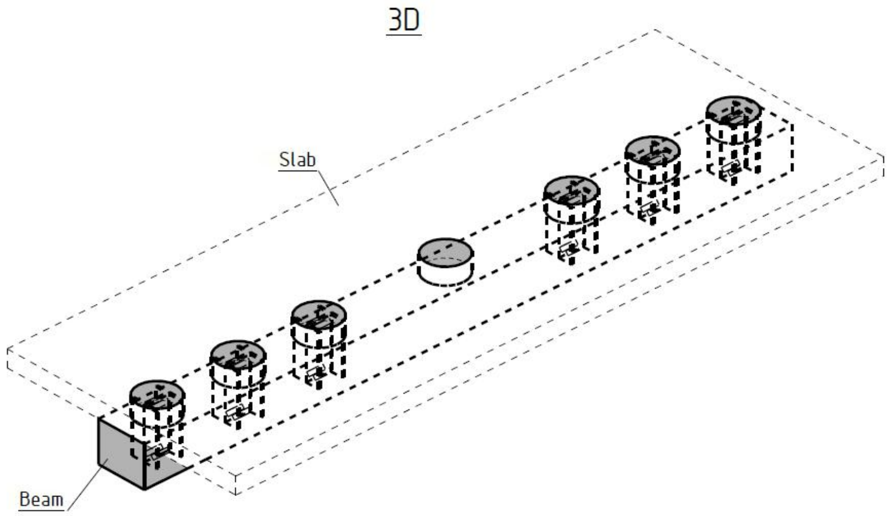

Fig. 5. 3D view of the strengthening beam

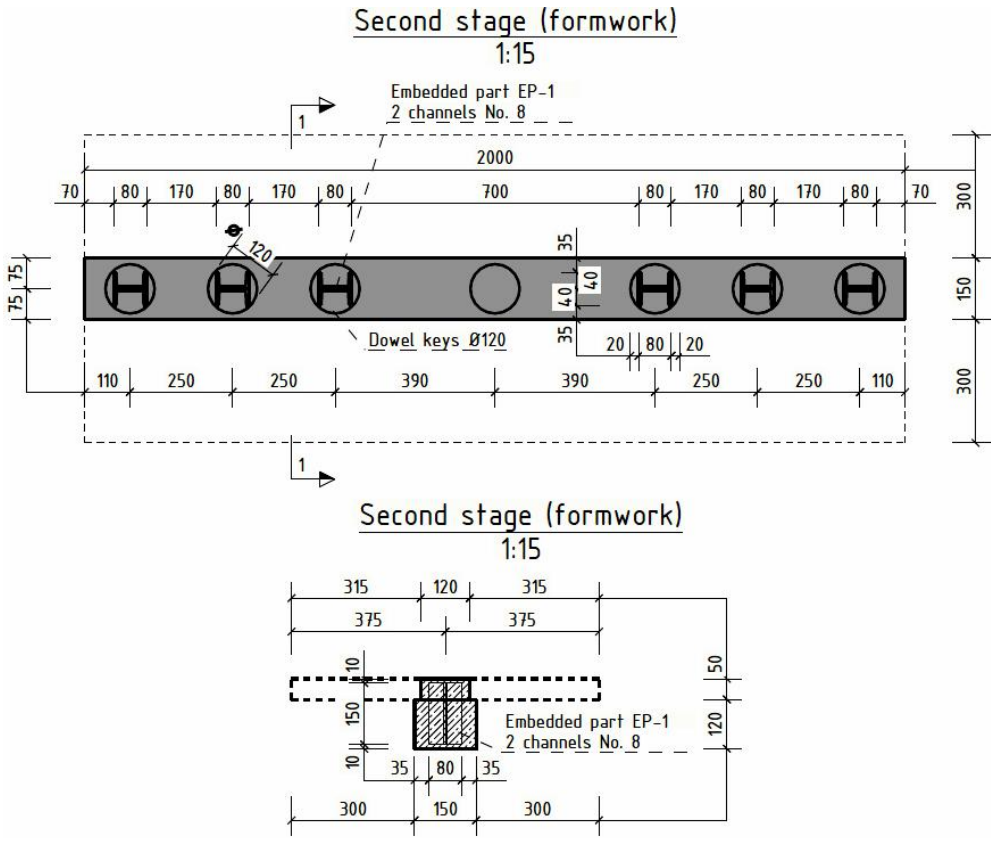

Fig. 6. Formwork drawing of the strengthening beam

– prevent cracking in the dowels after pouring and curing of concrete, as well as during the movement of the tested specimen;

– ensure the redistribution of shear forces between the slab and the beam.

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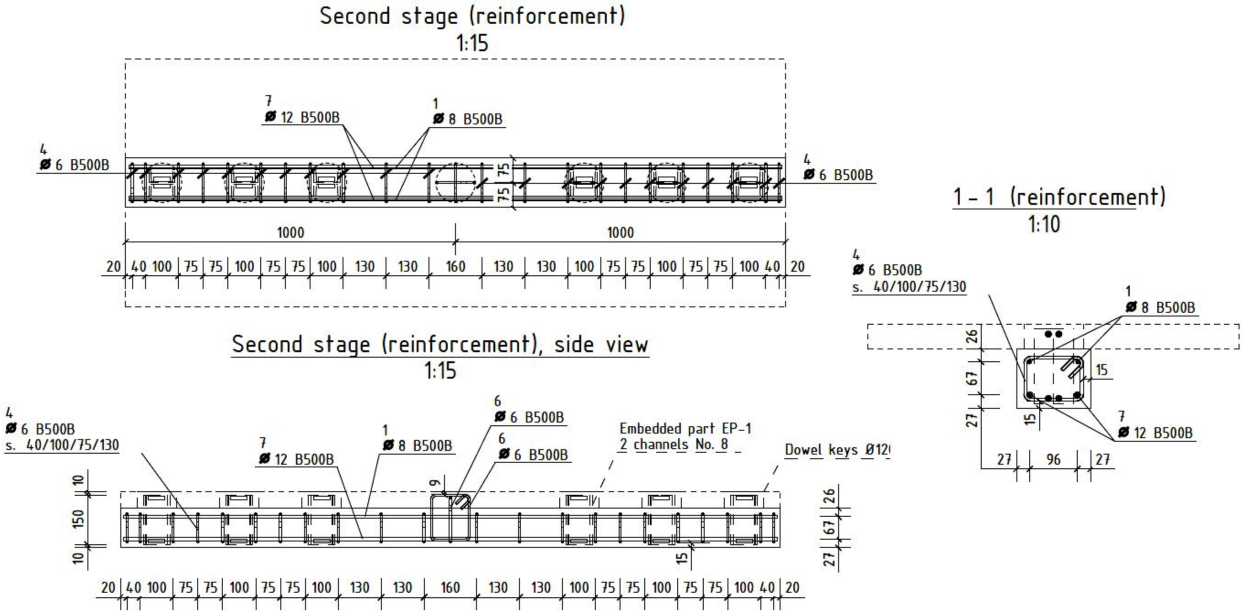

Fig. 7. Reinforcement of the strengthening beam

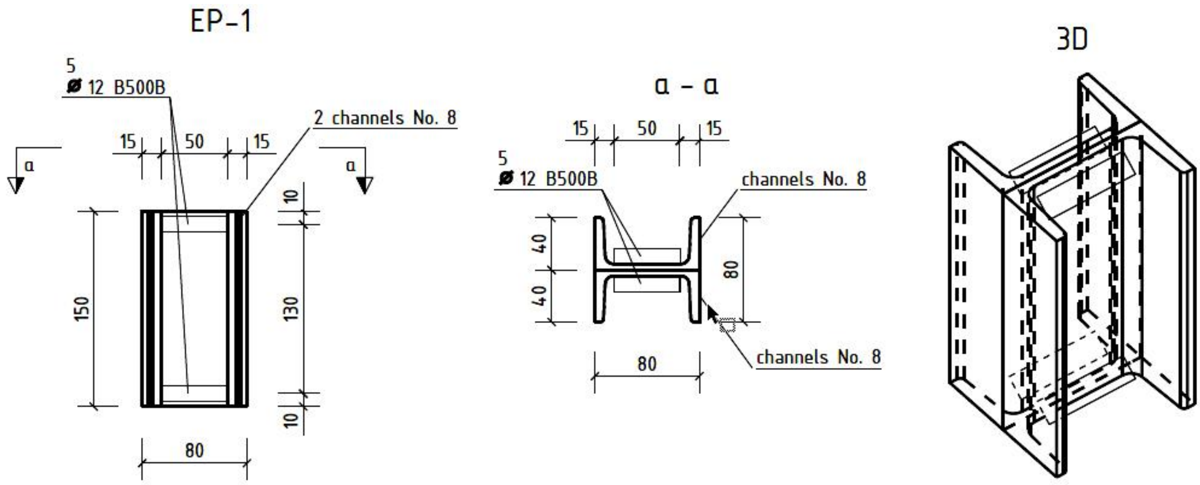

Fig. 8. Embedded part for the dowel

These embedded parts play a crucial role in the effective transfer of shear forces between the slab and the beam, contributing to the monolithic behavior of the entire system. Their placement and detailing are essential to prevent local damage around the dowels and to maintain structural continuity during loading. Moreover, proper execution at this stage sets the foundation for successful reinforcement and reliable performance of the strengthened slab in subsequent testing and application.

Results and discussions

In parallel with the laboratory specimens, numerical modeling was carried out in the LIRA-SAPR software package. To accurately reproduce the structural behavior, a nonlinear model was created in accordance with the provisions of EN 1992-1-1:2004 and national standard DSTU B V.2.6-156:2010, taking into account the geometry of the slab and beam, the arrangement of dowels, reinforcement, and the material properties of concrete and steel. Several variants were also modeled for comparison of results – a slab without reinforcement, a slab strengthened by a beam integrated through the openings, and a T-shaped section (reference specimen) (Fig. 9).

After performing the calculations, displacement and stress contour plots are presented for the slab without reinforcement (Fig. 10), the strengthened slab (Fig. 11), and the T-shaped section (Fig. 12). The calculation results (Table 3) demonstrate the influence of the strengthening beam on the slab's stiffness and strength. A comparison of displacement contours before and after strengthening shows a significant reduction in deflections. Analysis of the stress contours indicates the formation of a complex stress-strain state in the structure, which is characteristic of the dowel zones and the slab-beam contact area, emphasizing the necessity for careful design of the strengthening system.

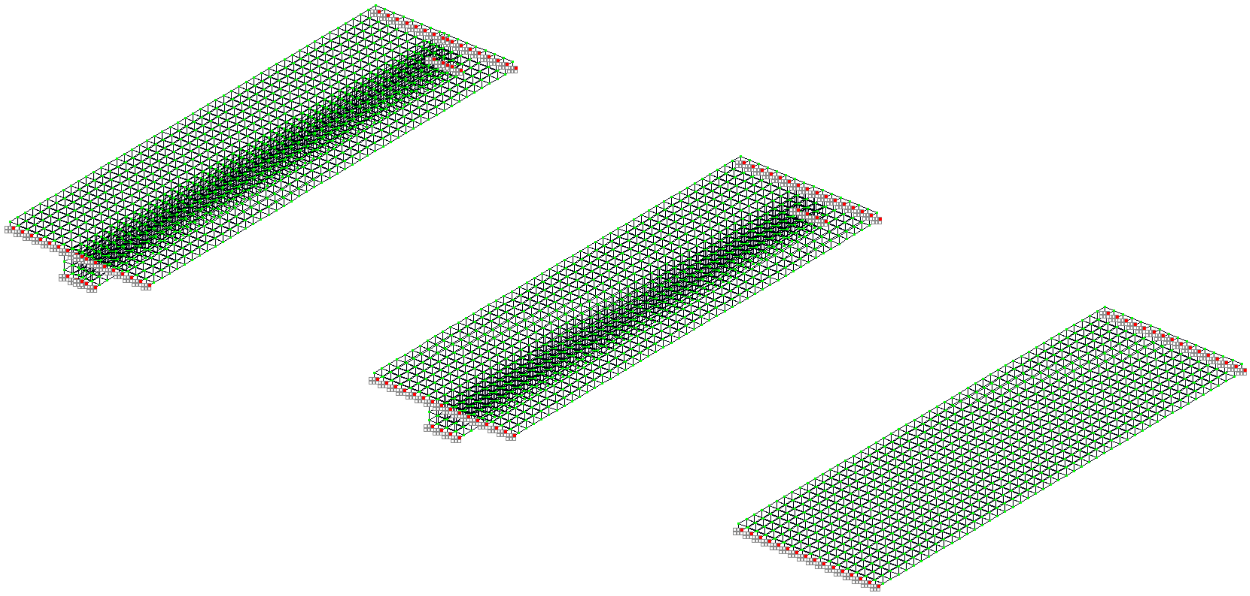

Fig. 9. Modeling in LIRA-SAPR software

Table 3

Results obtained in the LIRA Software

No. of Test Specimen	Description	Load, kN/m²	Deflection, mm
1	Slab without strengthening	4.00	4.78
2	Slab strengthened with dowels using I-beam / channel	4.00	0.296
3	T-beam cross-section	4.00	0.164

The combination of laboratory and numerical studies in the future will allow not only the verification of the strengthening effectiveness but also the identification of critical areas of the structure, the assessment of reinforcement and dowel parameters, and the formation of a reliable basis for the further practical implementation of reinforced concrete slab strengthening

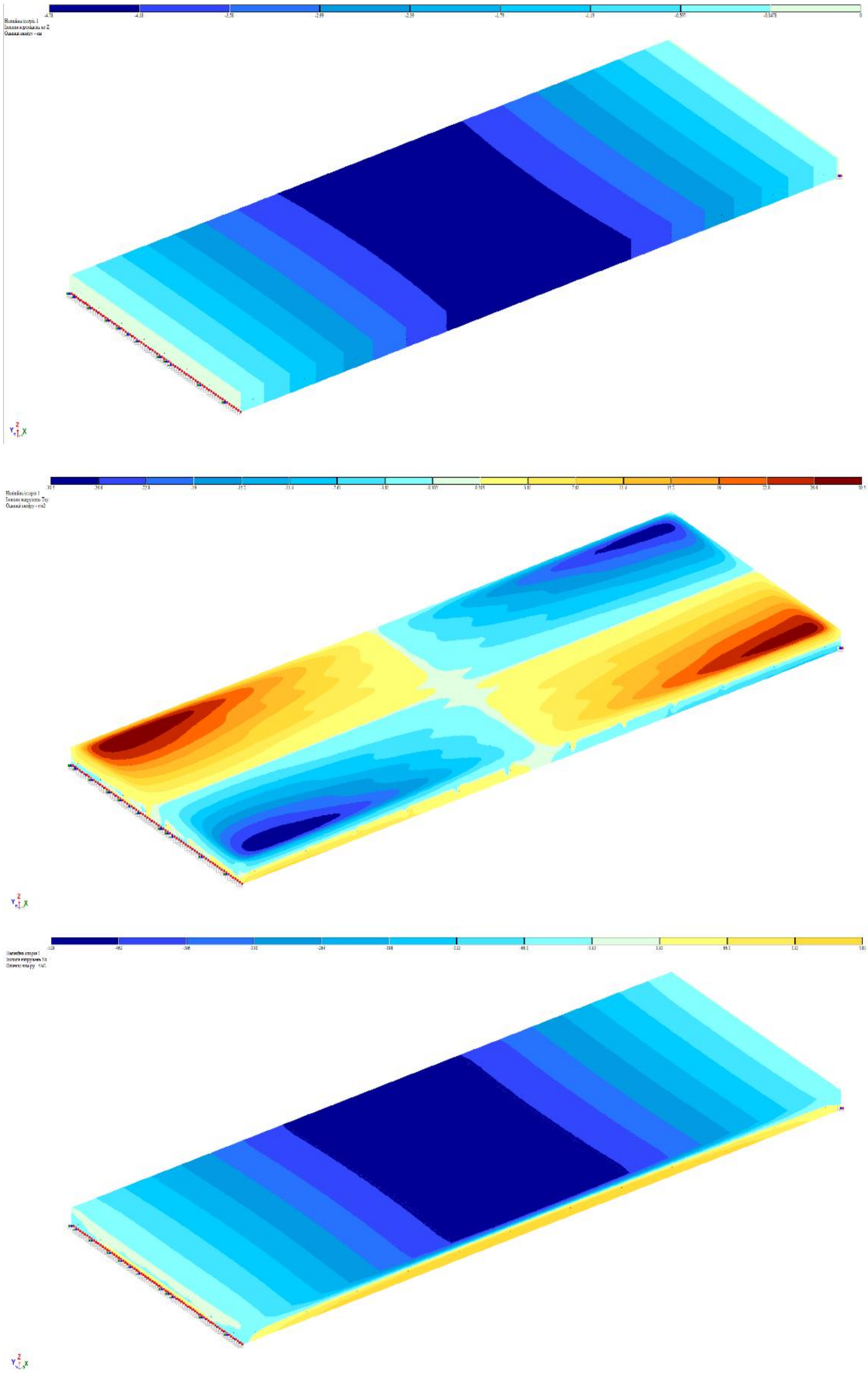

Fig. 10. Slab without strengthening. Displacement / stress Txy / stress Nx

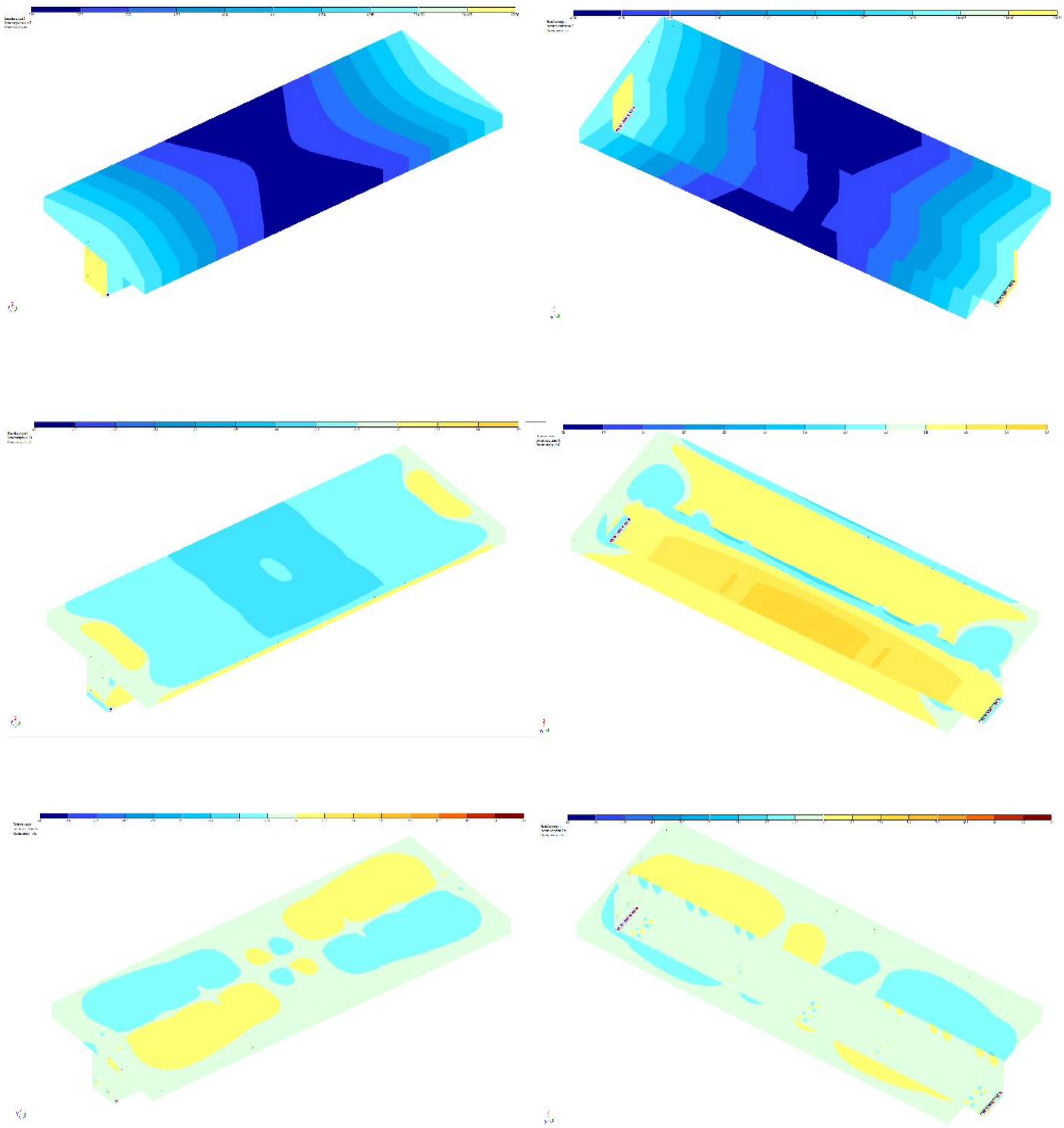

Fig. 11. Strengthened slab. Displacement / stress Txy / stress Nx

Conclusions

As a result of the conducted study, a method for strengthening reinforced concrete slabs was developed and theoretically substantiated by introducing additional beams through pre-formed openings. The analytical calculations and numerical modeling performed in the LIRA-SAPR software package demonstrated the high efficiency of the proposed technology. The analysis of the results showed that, after strengthening, the slab deflection significantly decreased, and its load-bearing capacity substantially increased. This confirms that the proposed method is a reliable and economically feasible solution for improving the performance of existing reinforced concrete floor systems.

It should be emphasized that the findings obtained at this stage are theoretical and numerically validated; experimental verification will be the next stage of research. The developed approach can therefore serve as a foundation for future laboratory investigations and practical recommendations for engineering design.

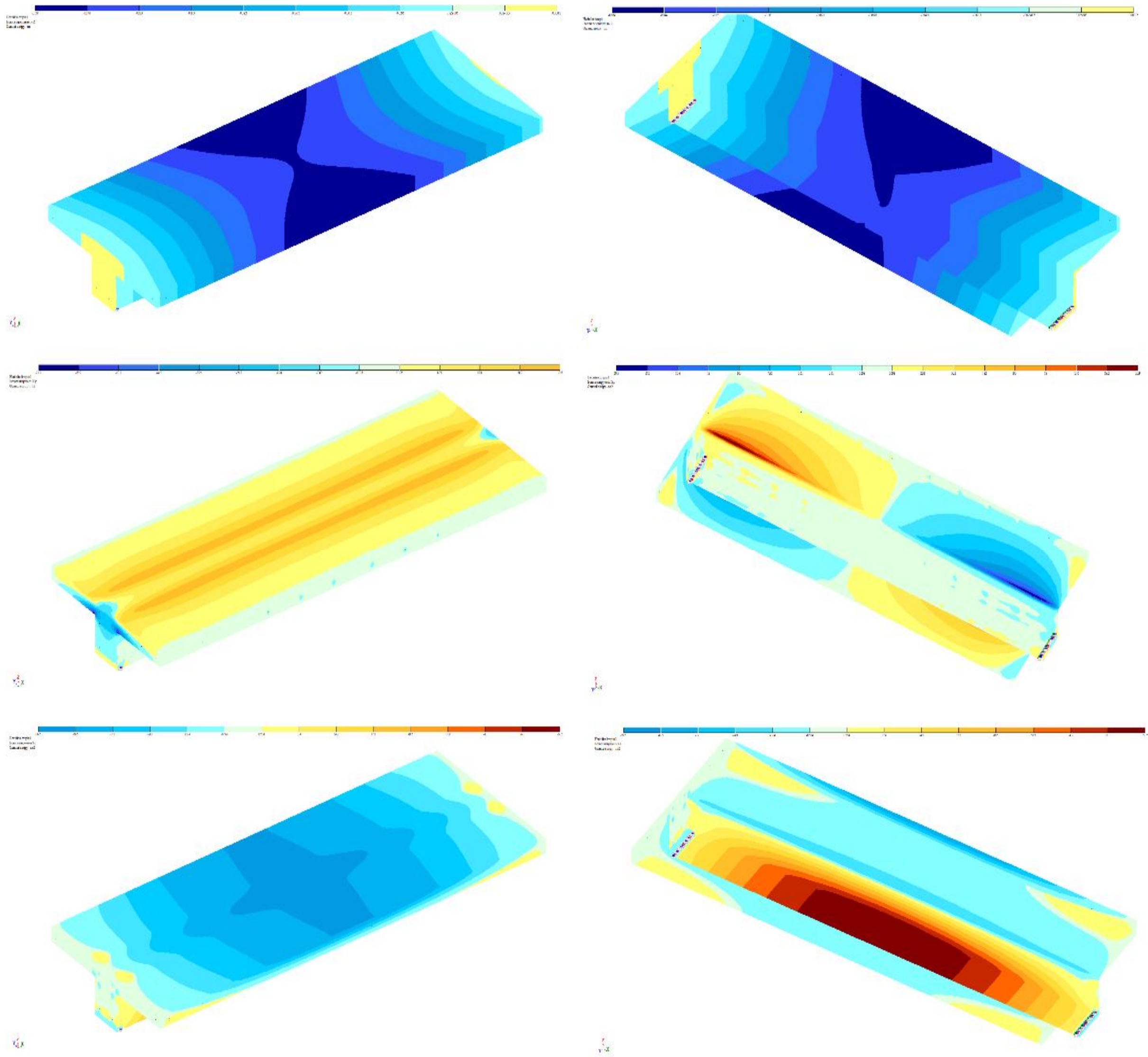

Fig. 12. T-beam cross-section. Displacement / stress Txy / stress Nx

The additional beams effectively redistribute loads and relieve stress concentrations in weakened areas of the slab, making this method a promising alternative to traditional, more expensive reconstruction techniques.

Future work will include experimental testing and assessment of durability and cyclic behavior of strengthened elements under varying load conditions to confirm and expand the theoretical results.

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ПІДСИЛЕННЯ ЗАЛІЗОБЕТОННИХ ПЛИТ ШЛЯХОМ ВЛАШТУВАННЯ МОНОЛІТНИХ БАЛОК: МЕТОДИ ТА РЕАЛІЗАЦІЯ

У статті досліджено ефективність підсилення залізобетонних плит уведенням додаткових монолітних залізобетонних балок за допомогою підмонолічування знизу. Розглянуто вплив такого підсилення на несучу здатність, деформаційні характеристики, розподіл внутрішніх напружень і загальну стійкість плит. Особливу увагу приділено механізмам передавання навантаження, зміні напружено-деформованого стану та взаємодії між наявною плитою і нововведеними балками, що забезпечує ефективну сумісну роботу конструкції.

Дослідження містить теоретичний аналіз і числове моделювання для оцінювання поведінки підсилених плит за рівномірно розподілених навантажень. Застосування попередньо влаштованих шпонок дає змогу досягти надійної сумісної роботи досліджуваної плити та балки. Раціональне розташування арматури, геометрія балок і підбір матеріалів сприяють оптимальному перерозподілу навантажень і зниженню концентрацій напружень.

Теоретичні результати числового моделювання свідчать про істотне зменшення прогинів, збільшення тріщиностійкості та зростання несучої здатності плит. Ефективність запропонованого підходу доведено на рівні аналітичних досліджень. Він може стати основою для подальших експериментальних перевірок та застосування у практиці підсилення конструкцій під час реконструкції або зміни умов експлуатації.

Ключові слова: плити, підсилення, прогин, реконструкція, міцність, ЛІРА-САПР.