Вісник Тернопільського національного технічного університету
https://doi.org/10.33108/visnyk_tntu
Scientific Journal of the Ternopil National Technical University
2025, № 2 (118) https://doi.org/10.33108/visnyk_tntu2025.02
ISSN 2522-4433. Web: ***visnyk.tntu.edu.ua***

UDC 624.012.36

EXPERIMENTAL STUDIES ON THE BEARING CAPACITY OF CROSS-REINFORCED CONCRETE BEAMS

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Abstract. *The article substantiates the relevance and necessity of further experimental research of reinforced concrete structures under biaxial compression. First, this concerns slab monolithic structures of floors with bidirectional arrangement of inserts and slab monolithic flat foundations. To solve the problem, three main types of test specimens were designed, manufactured and tested, which have a cross arrangement of beams. In addition, four types of conventional beams were manufactured, which consist of cross beams, and cubes and prisms to determine the actual deformation and strength characteristics of concrete. In the middle part of the beams in the zone of pure bending, only the lower working reinforcement is provided, which is adopted according to the results of verification calculations so that the destruction occurs in compressed concrete. Outside the zone of pure bending, the upper and transverse reinforcement are provided to prevent destruction in inclined sections. The geometric dimensions of the test specimens are adopted taking into account the design of the existing force stand and the technical characteristics of the test equipment. The linear and cross-section test specimens were loaded with two and four symmetrically located concentrated forces, respectively, using hydraulic jacks and force-distributing traverses. The loads were monitored by tared circular dynamometers mounted on supports. The experimental studies have shown that in the area of the cross-section of the beams, concrete is strengthened due to biaxial compression. The bearing capacity of the test specimens of linear beams compared to their bearing capacity in the composition of crossbeams is lower by 10.6-12.5%. An important parameter of the stress-strain state of compressed concrete is deformations, which are functionally related to its strength. The deformations of the test specimens of concrete, measured directly on the upper face in the area of the cross-section of the beams, are lower than ein the neighboring areas by an average of 19.8%, which confirms the effect of concrete strengthening. Threfore, biaxial compression affects the deformation characteristics of concrete and its strength.*

Key words: *reinforced concrete beams, biaxially compressed concrete, experimental studies, bearing capacity, deformations.*

https://doi.org/10.33108/visnyk_tntu2025.02.168 *Received 11.02.2025*

1. STATEMENT OF THE PROBLEM

Monolithic flat reinforced concrete floors are now increasingly used, especially in civil buildings (housing, offices, etc.). We also observe a tendency to increase the spans of such floors and their use in shopping and exhibition complexes and other structures. To significantly reduce the weight of flat monolithic reinforced concrete floors and other slab structures, it is advisable to use effective inserts as separate products made of relatively light and cheap materials, which are placed in the middle of the cross-section and left in the slab after its concreting. The modulus of elasticity and strength of the material of the inserts are an order of magnitude lower than that of concrete, therefore the space they occupy in the body of concrete should be considered a cavity for the structure.

Structural solutions of slab structures with such inserts can be divided into two types: with unidirectional arrangement of inserts and with bidirectional. With unidirectional, we obtain a monolithic slab structure with the arrangement of intermediate beams-ribs in one direction. Experimental and theoretical studies of such slab structures are widespread and

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are reflected, in particular, in works [1, 2]. Bidirectional arrangement of inserts forms another structural system in which the intermediate beams-ribs are usually arranged perpendicularly to each other. The concrete of the upper zone of the beams undergoes biaxial compression, which changes its initial deformation and strength characteristics of concrete. Recommendations for taking into account biaxial compression of concrete in slab structures have not been developed. It is necessary to conduct research on reinforced concrete structures with biaxial compression due to the orthogonal arrangement of beams.

2. ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Studies of biaxially compressed concrete were carried out mainly on individual cubic and prismatic elements [4–13].

The publication [14] presents data from experimental tests of reinforced concrete beams of rectangular profile made of heavy concrete in pure biaxial bending. The angle of inclination of the plane of external loading to the vertical axis of inertia of the section varied from 0º to 20º. The tests were carried out to study the operation of biaxial bending elements under load and to verify the developed method of strength analysis of such elements.

In the article [15], based on the design assumptions according to Eurocode 2, a concept for determining the value of the design strength of reinforced concrete for calculating the bearing capacity of reinforced concrete elements subjected to biaxial bending was developed. However, experimental [14] and theoretical [15] studies were carried out on individual beam elements under oblique bending and do not apply to slab structures.

The publication [17] presents the results of studies under high-speed dynamic loading. The considered dynamic effects are not characteristic of the slab reinforced concrete structures under consideration.

Based on the results of the studies [18], a model was proposed that describes the relationship between stresses and strains in biaxial compression. However, it concerns recycled concrete and cannot be used for ordinary concrete.

In the publication [3], calculation schemes for calculating slab structures with bidirectional arrangement of inserts are substantiated using analytical dependencies obtained in studies on concrete prisms. However, they require experimental confirmation for reinforced concrete structures, the concrete of which is subjected to biaxial compression.

The objective of the work is to experimentally investigate the bearing capacity of reinforced concrete structures subjected to biaxial compression of concrete.

3. TASK STATEMENT

To investigate the effect of biaxially compressed concrete on the strength of reinforced concrete beams when tested on a force bench under static loads.

4. DESIGN OF TEST SAMPLES

To solve the problem, three main types of experimental specimens with a cross arrangement of beams were designed, manufactured and tested. In addition, four types of conventional beams were manufactured, which make up the cross beams.

The designs of the linear beam of the L-1 brand (which is an element of the crossbeam) and the crossbeam of the LP-1 brand are shown in Fig. 1.

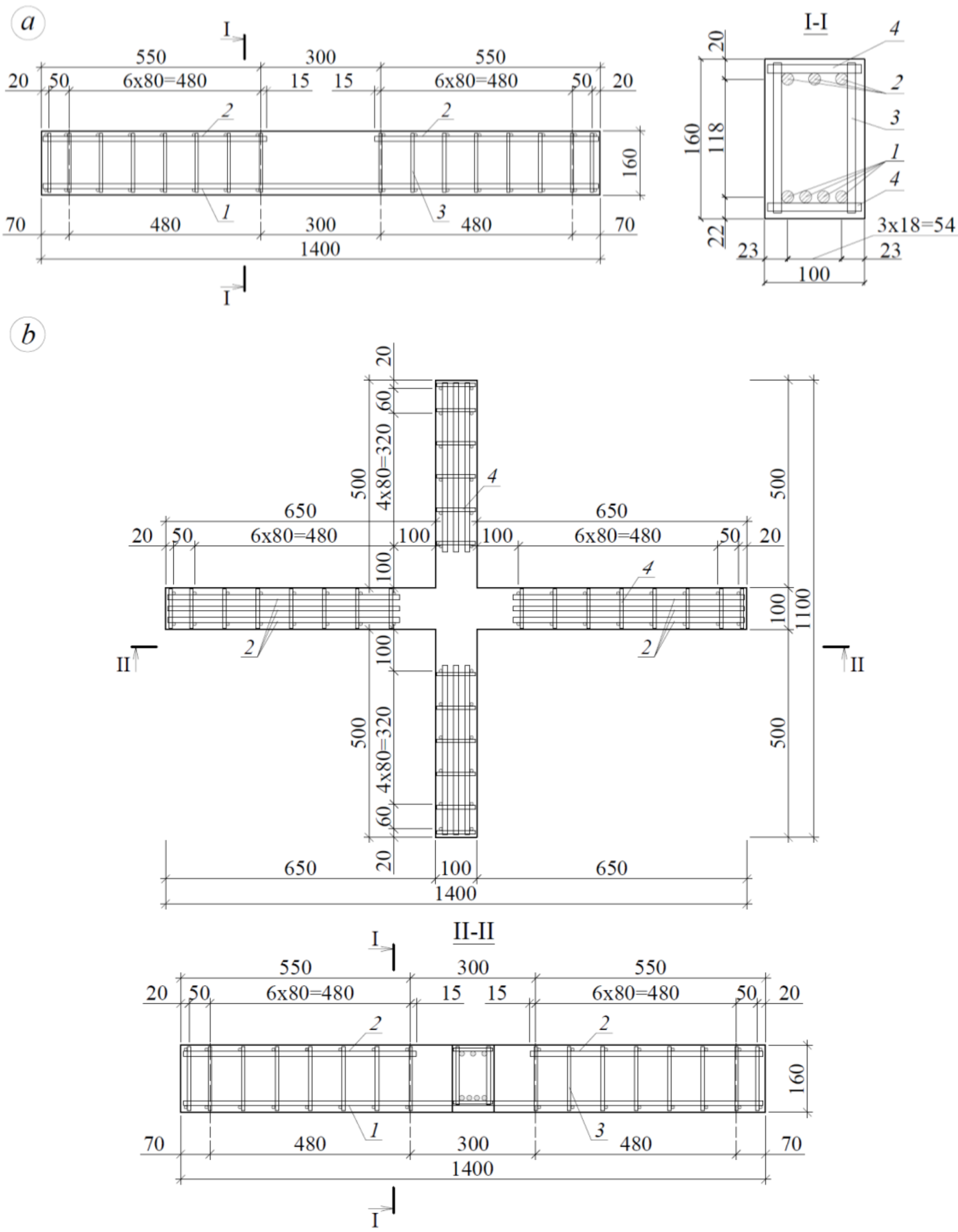


Figure 1. Design of prototypes of the L-1 brand (a) and LP-1 brand (b)

In the middle part of the beams in the zone of pure bending, only the lower working reinforcement is provided, which is adopted according to the results of calculations so that the failure occurs along the compressed concrete. Outside the zone of pure bending, the upper and transverse reinforcement are provided to prevent failure along inclined sections.

The beams are designed so that the failure occurs in the zone of pure bending due to crushing of concrete.

The general design of the experimental specimen L-2 is similar to the design of the beam L-1 with the following differences: length 1.1 m; in section I–I the distance to the axis of the lower reinforcement is 36 mm. In section III–III, the general design is similar to section II–II.

For the manufacture of beams, reinforcement of class A500 and concrete of design class C25/30 with the following actual characteristics were used: fcube = 29.2…30.3 MPa; fprism = 24.3…25.7 MPa. Longitudinal upper and lower reinforcement diameter 12 mm, transverse – ∅ 8 mm.

5. EXPERIMENTAL RESEARCH METHODOLOGY

Linear and cross-section test specimens were loaded with two and four symmetrically located concentrated forces, respectively, using hydraulic jacks and force-distributing traverses (Fig. 2). The loads were controlled by tared circular dynamometers mounted on supports.

a b

Figure 2. General view of the tests: a – linear prototype of the L-2a brand; b – cross prototype of the LP-2 brand

To measure deformations of reinforcement, concrete, and vertical displacements, mechanical clock-type devices with a measurement accuracy of 0.001 mm and 0.01 mm, respectively, were used.

6. RESULTS OF EXPERIMENTAL RESEARCH AND THEIR DISCUSSION

All linear test specimens collapsed due to crushing of the concrete of the upper layers of the beams in the zone of pure bending (Fig. 3).

The nature of the collapse of the cross beams was different. They also collapsed in the zones of pure bending. However, the collapse did not begin at the intersection of the beams (a section measuring 10×10 cm), but near this section on one of the linear beams (Fig. 4). This, in principle, proves that in the area of the intersection of the beams, concrete strengthening occurs due to biaxial compression.

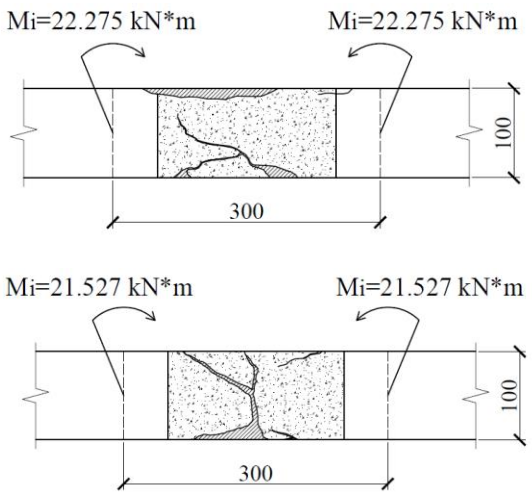
At failure, the values of the moments in the shorter beam in relation to the moments in the longer beam were: in the experimental sample LP-1 – 0.723; in the experimental sample LP-2 – 0.764; in the experimental sample LP-3 – 0.757. The average value of this ratio is 0.748 ≈ 0.75.

The total destructive load of the separately tested linear beams L-1 and L-2a is 18.63 kH. The destructive load of the sample LP-1 (which consists of beams L-1 and L-2a) is 20.577 kH and is 10.6% higher.

Using a similar approach, the increase in bearing capacity for sample LP-2 is 12.5%, for sample LP-3 – 11.8%.

Therefore, the total bearing capacity of linear beams tested separately is 10.6–12.5% lower as compared to their bearing capacity as part of cross-section test specimens.

In addition to the direct bearing capacity of test specimens, the stress-strain state of concrete in the pure bending zone was also analyzed.



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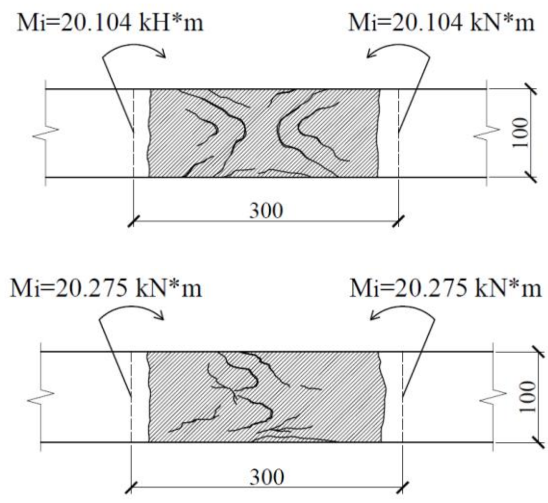
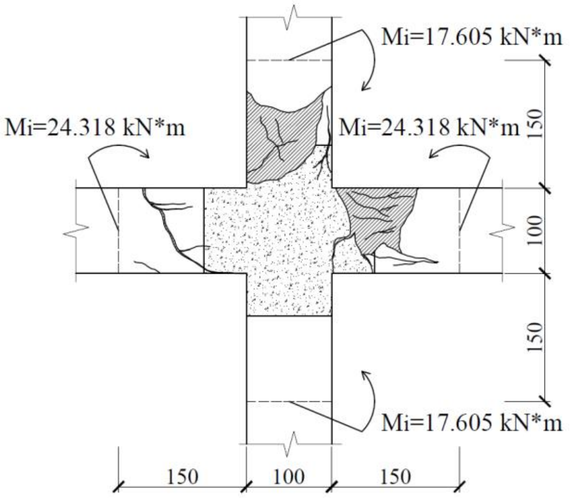


d

Figure 3. Destruction of the compressed zone of concrete of linear beams: a – beams L-1; b – beams L-2a; c – beams L-2b; d – beams L-2c



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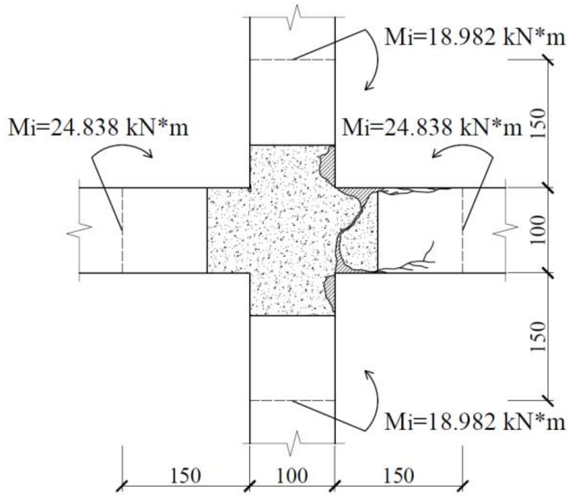
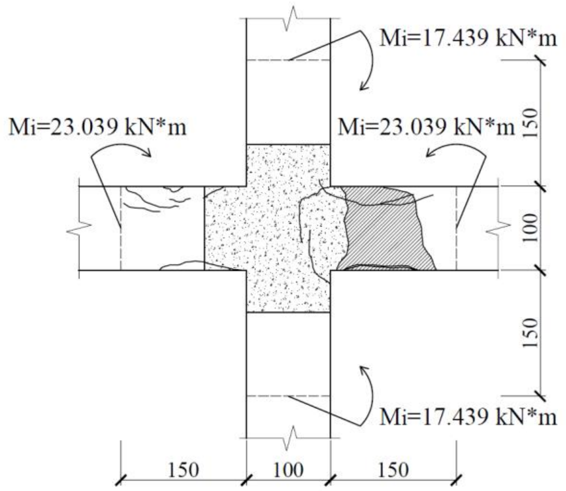


b



c

Figure 4. Destruction of the compressed zone of concrete of cross beams: a – beams LP-1; b – beams LP-2; c – beams LP-3

Fig. 5 and 6 show comparative graphs of concrete deformations of cross beams LP-1 in the zone and near their intersection zone. Clock-type indicators installed on different bases measured deformations on each beam. On the longer beam, indicator I-1 on a 120 mm base, indicator I-3 on a 220 mm base.

Similarly, for the shorter beam, indicators I-2 on a 120 mm base and I-4 on a 240 mm base were installed.

Thus, indicator I-1 recorded only deformations at the intersection of the beams, and indicator I-3 – deformations both at the intersection and beyond the intersection on both sides.

From the comparison of the graphs it is clear that the relative deformations ε_1 are smaller than the deformations ε_3 (Fig. 5), and the deformations ε_2 are smaller than the deformations ε_4 (Fig. 6).

Similar results were obtained for the cross-sectioned test specimens LP-2 and LP-3. The difference is from 11.7% to 29.3%.

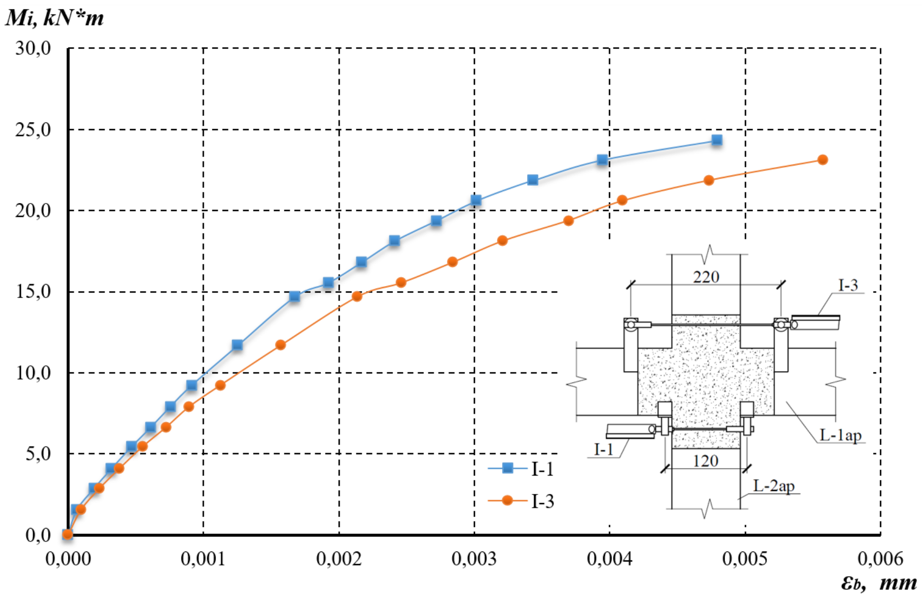


Figure 5. Graphs of relative deformation of concrete of beam L-1ap

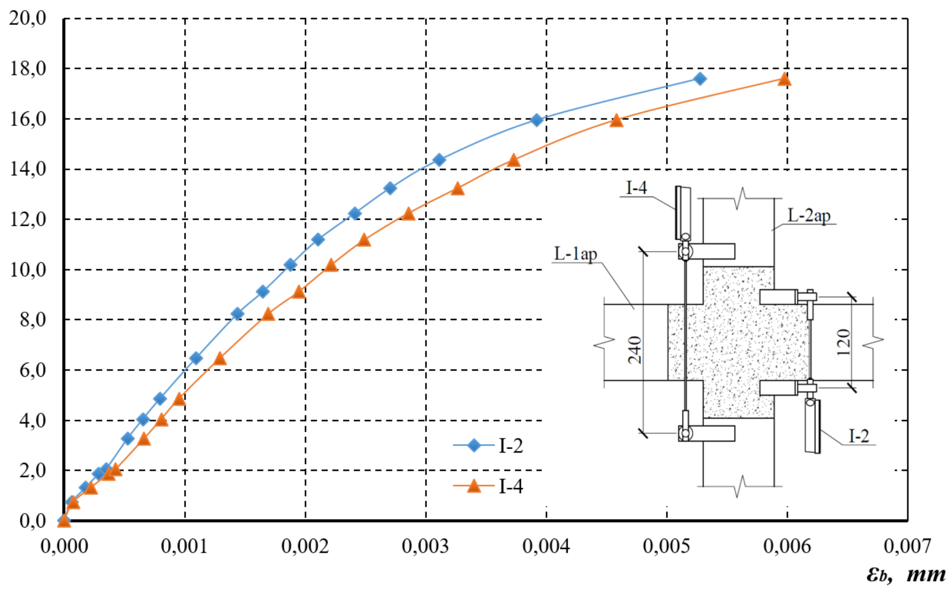


Figure 6. Graphs of relative deformation of concrete of beam L-2ap

7. CONCLUSIONS

1. Experimental studies have shown that in the area of the beam intersection, concrete is strengthened due to biaxial compression. The bearing capacity of the experimental samples of linear beams compared to their bearing capacity in the composition of cross beams is 10.6–12.5% lower.

2. An important parameter of the stress-strain state of compressed concrete is deformation, which is functionally related to its strength. The deformations of the concrete of the test specimens, measured directly on the upper face at the intersection of the beams, are smaller than in the neighboring areas by an average of 19.8%, which confirms the effect of concrete strengthening.

3. Experimental studies were performed at a moment ratio in cross beams M1/M2 = 0.75. It is advisable to continue the study of reinforced concrete structures with biaxially compressed concrete at other moment ratios M_1 to M_2 (in particular 0.5 and 1.0) to obtain functional dependencies in a wider range.

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УДК 624.012.36

ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ НЕСУЧОЇ ЗДАТНОСТІ ПЕРЕХРЕСНИХ ЗАЛІЗОБЕТОННИХ БАЛОК

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Резюме. *Обґрунтовано актуальність та необхідність подальших експериментальних досліджень залізобетонних конструкцій при двовісному стиску. Насамперед це стосується плитних монолітних конструкцій перекриттів і плитних монолітних плоских фундаментів з двонаправленим розташуванням вставок. Для вирішення поставленого завдання запроектовано, виготовлено й досліджено три основних типи дослідних зразків, які мають перехресне розташування балок. Крім цього, виготовлено чотири типи звичайних балок, з яких складаються перехресні балки, куби та призми для визначення фактичних деформаційних і міцнісних характеристик бетону. В середній частині балок у зоні чистого згину передбачено лише нижню робочу арматуру, яка прийнята за результатами перевірних розрахунків так, щоб руйнування відбулося по стисненому бетону. Лінійні й перехресні дослідні зразки навантажували відповідно двома і чотирма симетрично розташованими зосередженими силами з використанням гідравлічних домкратів і силороздільних траверс. Проведені експериментальні дослідження показали, що на ділянці перетину балок відбувається зміцнення бетону внаслідок двовісного обтиску. Несуча здатність дослідних зразків лінійних балок порівняно з їх несучою здатністю в складі перехресних балок є меншою на 10,6–12,5%. Деформації бетону дослідних зразків, заміряні безпосередньо на верхній грані на ділянці перетину балок, є меншими, ніж на сусідніх ділянках у середньому на 19,8%, що підтверджує ефект зміцнення бетону. Отже, двовісний стиск впливає на деформаційні характеристики бетону і його міцність.*

Ключові слова: *залізобетонні балки, двовісно стиснений бетон, експериментальні дослідження, несуча здатність, деформації.*

https://doi.org/10.33108/visnyk_tntu2025.02.168 *Отримано 11.02.2025*