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METHODS OF EXPERIMENTAL RESEARCH OF REINFORCED CONCRETE BEAMS REINFORCED WITH POST-TENSIONED ROPES

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Abstract. The article presents a methodology for conducting experimental studies of reinforcing reinforced concrete beams using prestressed reinforcing ropes. The developed methodology is based on the principle of reinforcing elements, which allows increasing their bearing capacity and crack resistance without the need for dismantling or significant intervention in the existing structure.

The main attention is paid to the technical aspects of implementing prestressing ropes, in particular, methods of their fastening, tension parameters, and methods of controlling the stressed state. The work presents the sequence of conducting the experiment, which includes the manufacture of a series of test specimens, their loading schemes, methods of measuring deformations and fixing the development of cracks.

At this stage of the study, the development, manufacture, and installation of a test rig designed to simulate the operation of reinforced reinforced concrete elements under various loading conditions were carried out. The created experimental base provides the possibility of further conducting a series of tests aimed at qualitative and quantitative assessment of the influence of prestressed ropes on the stressed-deformed state of beams and determining the effectiveness of the proposed reinforcement technology. The results obtained in the future will become the basis for the formation of practical recommendations and improvement of calculation methods for reinforced concrete structures.

The main goal of this work is to promote the development and implementation of this technology. The research is aimed at improving the methodology for strengthening reinforced concrete structures and creating scientific prerequisites for updating the regulatory framework, which will ensure effective design, increasing the reliability and durability of construction projects in Ukraine.

Keywords: reinforcement; prestressing; post-tension; ropes; methodology.

INTRODUCTION

In the conditions of modern reconstruction and technical renewal of Ukraine, the problem of restoration and strengthening of existing reinforced concrete structures that have partially or completely lost their operational characteristics is of particular relevance. Many structures erected in the second half of the 20th century today do not meet modern requirements for strength, rigidity and crack resistance.

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The reasons for this are the natural aging of materials, corrosion of reinforcement, prolonged action of loads, as well as the influence of an aggressive environment. An additional factor that significantly complicated the situation was the destruction and damage of objects as a result of military operations, which creates an urgent need to implement quick and reliable solutions for their restoration and strengthening without complete dismantling.

Traditional strengthening methods, such as increasing the cross-section or installing steel plates, have significant disadvantages: they increase the mass of the element, complicate installation, and often require the cessation of operation of the structure. In this context, a promising direction is the use of prestressed ropes, which allow increasing the bearing capacity and crack resistance of reinforced concrete elements without significant intervention in their design. Such a method allows redistributing internal forces, reducing deformations, limiting the opening of cracks, and ensuring an increase in the service life of elements that have lost part of their bearing capacity.

At the same time, in Ukraine, relatively few studies have been carried out in the field of strengthening reinforced concrete structures using prestressing [1…13]. However, this technology is quite widespread in foreign practice [14…21]. Some works are devoted to general issues of prestressing in new construction or analysis of the operation of elements with composite reinforcement, but experimental studies of reinforcement with cables remain limited. The lack of systematized methods and scientifically based recommendations in this area necessitates the creation of our own experimental base and adaptation of world experience to Ukrainian conditions.

Thus, this work is aimed not only at improving modern design solutions, but also at scientifically substantiating and developing a methodology for experimental research of the processes of strengthening reinforced concrete elements using prestressed cables. The proposed methodology is universal and can be used both in the design of new structures and during the reconstruction or restoration of buildings with reduced load-bearing capacity or in a state of emergency.

An important direction of development of strengthening technologies in Ukraine is the systematic updating and harmonization of national regulatory documents [21…24] with modern European standards [25]. Such consistency of the regulatory framework will not only ensure compliance with international requirements, but also create the prerequisites for more effective implementation of innovative methods of strengthening existing structures, in particular with the use of pre-stressed ropes. Thanks to this, it will be possible to implement advanced technologies for restoration and reconstruction of building elements in accordance with modern safety and reliability standards.

MAIN IDEA

The main concept of the study involves combining traditional internal reinforcement with external post-tensioning of cables, which allows to significantly increase the bearing capacity of reinforced concrete beams, reduce deflections and limit the development of cracks without significant intervention in the structural system. This approach ensures the compatible operation of materials in tension and compression zones and contributes to a more uniform redistribution of bending moments in the middle of the spans. The main scientific and practical idea is to assess the effectiveness of reinforcement for both simple single-span beams and more complex double-span structures, where the interaction of spans and the redistribution of internal forces play a significant role.

The experimental program involves testing two series of beams, each of which includes both control specimens without reinforcement and specimens with prestressed cables. Series I consists of single-span beams, which allows us to study the behavior of the elements under pure bending conditions. Series II includes double-span beams, which allows us to evaluate the effectiveness of reinforcement under conditions of redistribution of bending moments between spans and more complex interaction of materials.

The beams are made of concrete of class C20/25, which is traditionally used in the performance of works on strengthening and repairing existing structures, and are reinforced with Ø10 A500C to ensure the compatibility of materials in the tension and compression zones. External prestressed cables Ø15.7 mm were fixed in anchor devices and tensioned to the design force determined on the basis of analytical calculations and in accordance with international design practice.

The reinforcement schemes of the beams of the first and second series are shown in Fig. 3–6. In the event of changes in loading conditions, deviations in the strength of materials, or the need to increase the accuracy of the comparative analysis of structures, the reinforcement scheme of the beams in the second series can be modified to ensure the reliability and representativeness of the experimental results.

The test scheme for single-span and double-span beams is shown in Fig. 1 and 2. The beams will be loaded using a hydraulic jack connected to a single working circuit with an oil station.

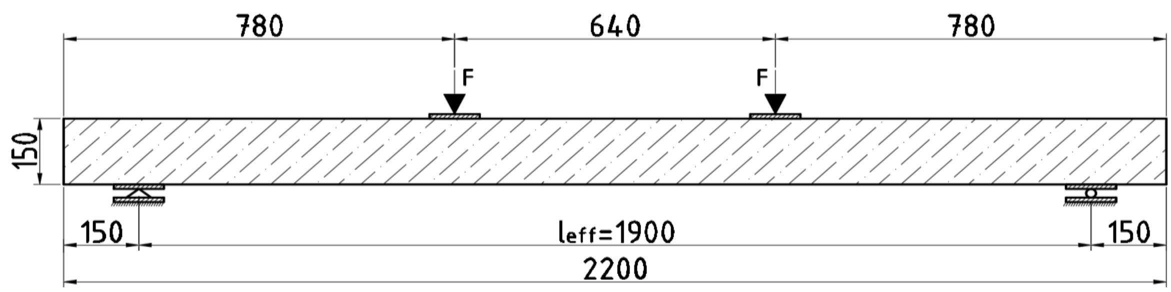

Fig. 1 Schematic diagram of the pure bending test of single-span beams of series 1
Рис. 1 Принципова схема випробування однопролітних балок серії 1 на чистий згин

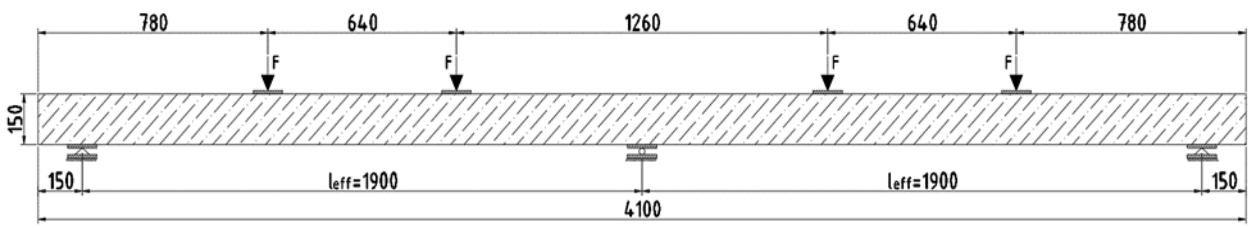

Fig. 2 Schematic diagram of the pure bending test of two-span beams of series 2
Рис. 2 Принципова схема випробування двопролітних балок серії 2 на чистий згин

The loading process will be carried out in stages with a uniform increase in the load, while the indicators of all measuring devices will be constantly recorded for further analysis. This approach ensures accurate recording of the moments of formation of the first cracks, their propagation and interaction with the internal reinforcement, and also makes it possible to assess the influence of external reinforcement on the change in the stress-strain state. Additionally, the experimental scheme involves measuring deflections at key points of the span, controlling the width and development of cracks, as well as recording stresses in the ropes and internal reinforcement using sensors, which ensures high accuracy and representativeness of the obtained data.

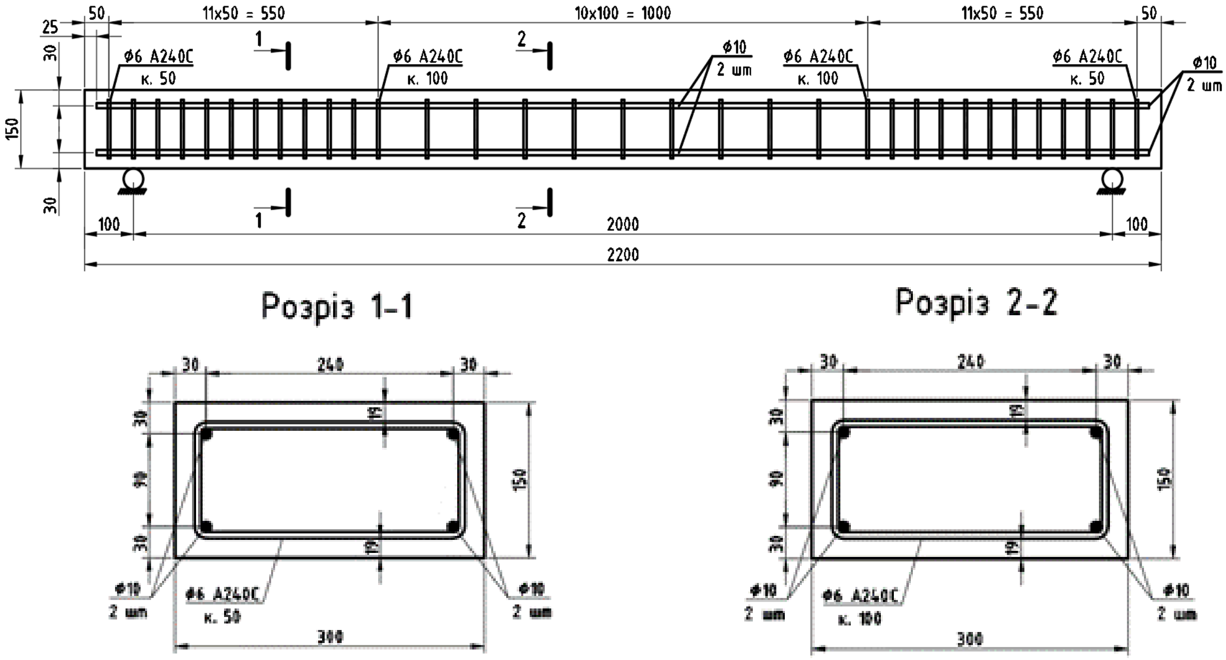

Fig. 3 Schematic diagram of reinforcement of single-span beams B-1.1 series 1
Рис. 3 Принципова схема армування однопролітних балок Б-1.1 серії 1

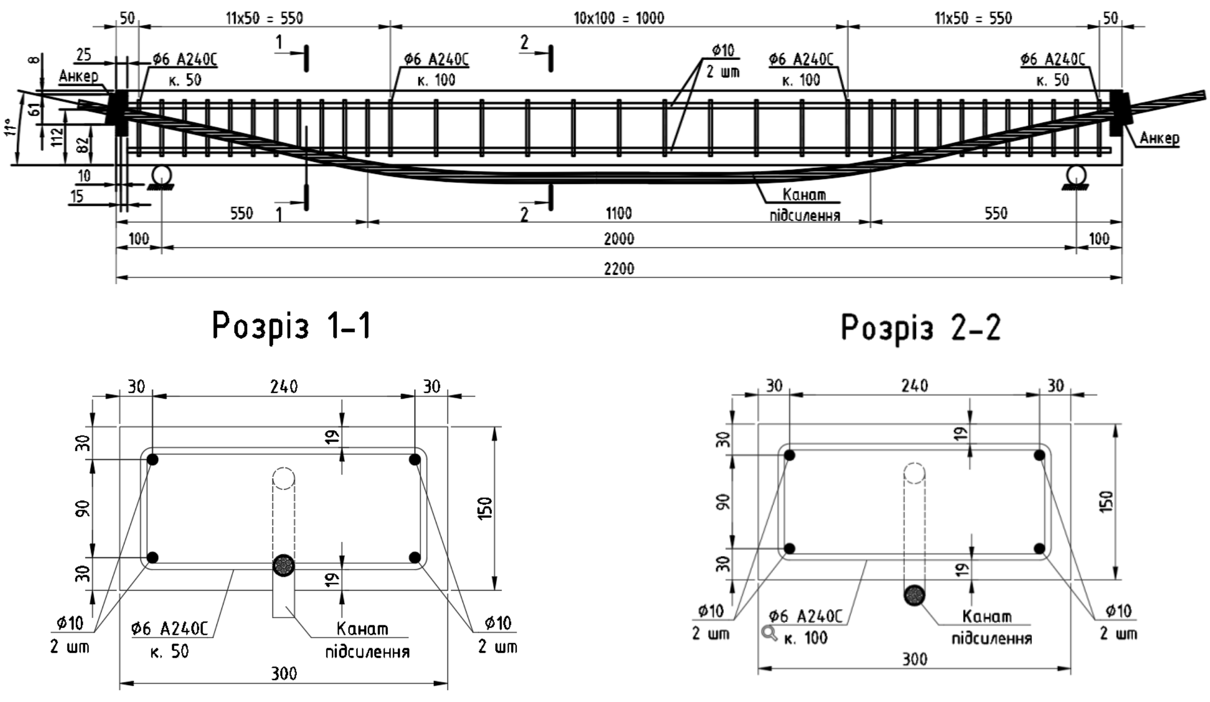

Fig. 4 Schematic diagram of reinforcement of reinforced single-span beams B-1.2 series 1
Рис. 4 Принципова схема армування підсилених однопролітних балок Б-1.2 серії 1

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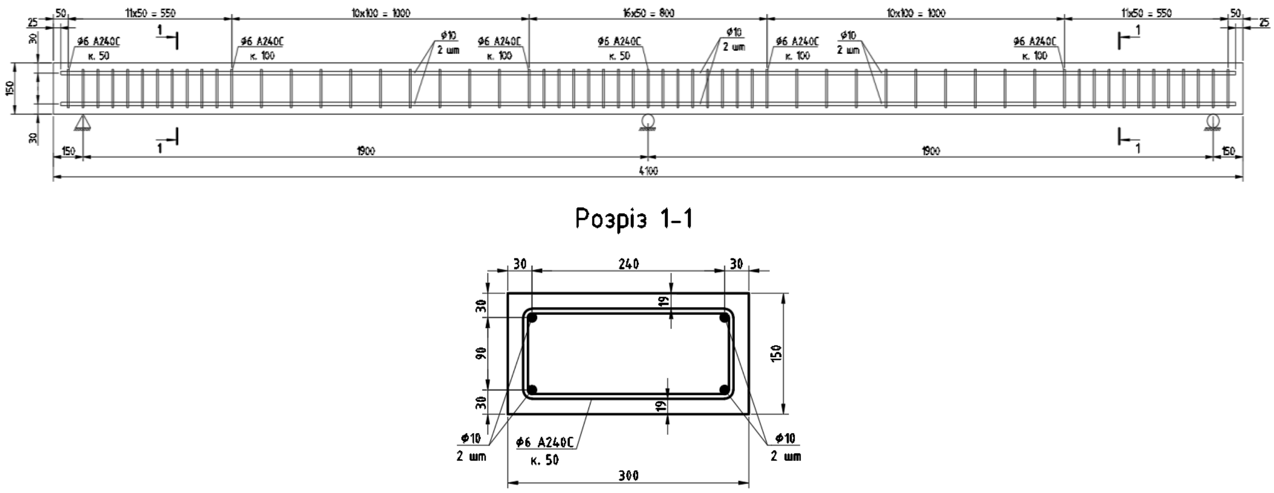


Fig. 5 Schematic diagram of reinforcement of double-span beams B-2.1 series 2
Рис. 5 Принципова схема армування двопролітних балок Б-2.1 серії 2

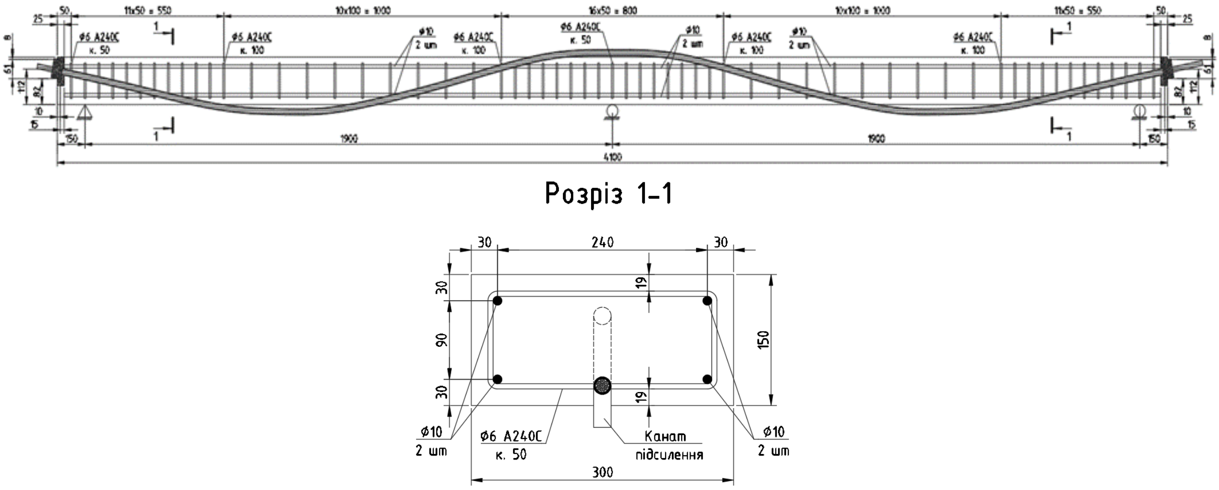
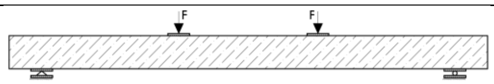
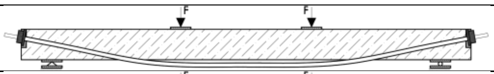
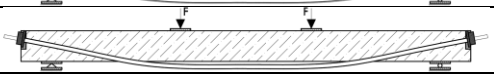
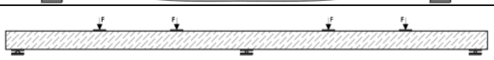
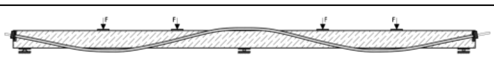


Fig. 6 Schematic diagram of reinforcement of reinforced double-span beams B-2.2 series 2
Рис. 6 Принципова схема армування підсилених двопролітних балок Б-2.2 серії 2

Table 1. Volumes and characteristics of the samples studied
Табл. 1. Обсяги та характеристика дослідних зразків

Series	Marking beams	Amount	Test scheme	Notes
1	B-1.1	2		Single-span beams without reinforcement see Fig. 7
	B-1.2	2		Single-span beams with rope reinforcement see Fig. 8
	B-1.3	2		Reinforced single-span beams B-1.1 with ropes after testing
2	B-2.1	2		Double-span beams without reinforcement see Fig. 9
	B-2.2	2		Double-span beams with rope reinforcement see Fig. 10
	B-2.3	2		Reinforced double-span beams B-2.1 with ropes after testing

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Series I – single-span beams without reinforcement and with reinforcement

Series I includes single-span beams, which are made in two versions: control specimens without reinforcement (see Fig. 7) and specimens with prestressed cables (see Fig. 8). This structure of the series allows to evaluate the effectiveness of reinforcement under simple conditions of pure bending and to form a basis for comparison with more complex structures.

Beam dimensions: 300x150(h)x2200 mm

Tasks of Series I:

- To record the relationship between the applied load, deflections and crack development.
- To determine the moment of formation of the first cracks and to trace the patterns of their propagation under the action of the load.
- To assess the stiffness and bearing capacity of beams without reinforcement and with reinforcement, which makes it possible to compare the effectiveness of the applied technology.
- To conduct a detailed analysis of the stress-strain state and the interaction of internal reinforcement and external ropes in reinforced samples.

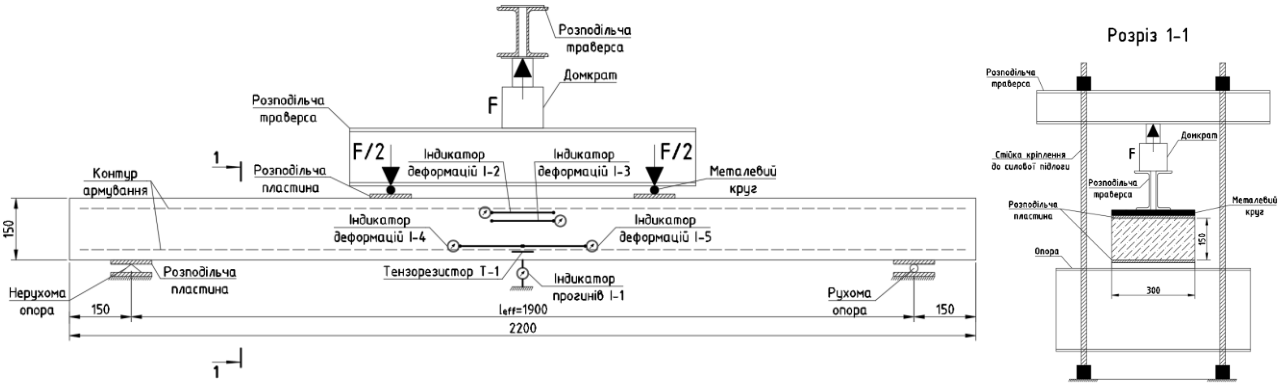

Fig. 7 Test scheme for single-span beam B-1.1 series 1
Рис. 7 Схема випробування однопролітної балки Б-1.1 серії 1

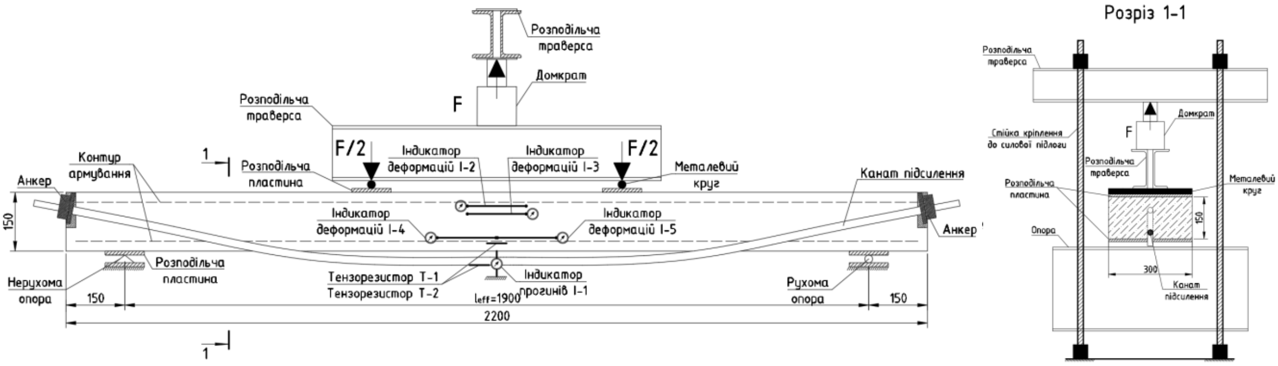

Fig. 8 Test scheme for reinforced single-span beam B-1.2 series 1
Рис. 8 Схема випробування підсиленої однопролітної балки Б-1.2 серії 1

Series II – double-span beams without reinforcement and with reinforcement

Series II involves testing two-span beams, which are also made in two versions: control specimens (see Fig. 9) and specimens with prestressed cables (see Fig. 10). The study of two-span beams allows us to study the redistribution of bending moments between the spans and the interaction of materials in more complex structures, close to real operating conditions.

Beam dimensions: 300x150(h)x4100 mm (two spans of 1900 mm)

<u>Tasks of Series II:</u>

- To investigate the effect of external reinforcement on the development of cracks, deflections and redistribution of bending moments between spans.
- To determine changes in the stress-strain state and load-bearing capacity of double-span beams compared to control samples.
- To obtain data for comparing the effectiveness of reinforcement of single-span and double-span beams, which is important for the development of methodological recommendations for the reconstruction of existing buildings.

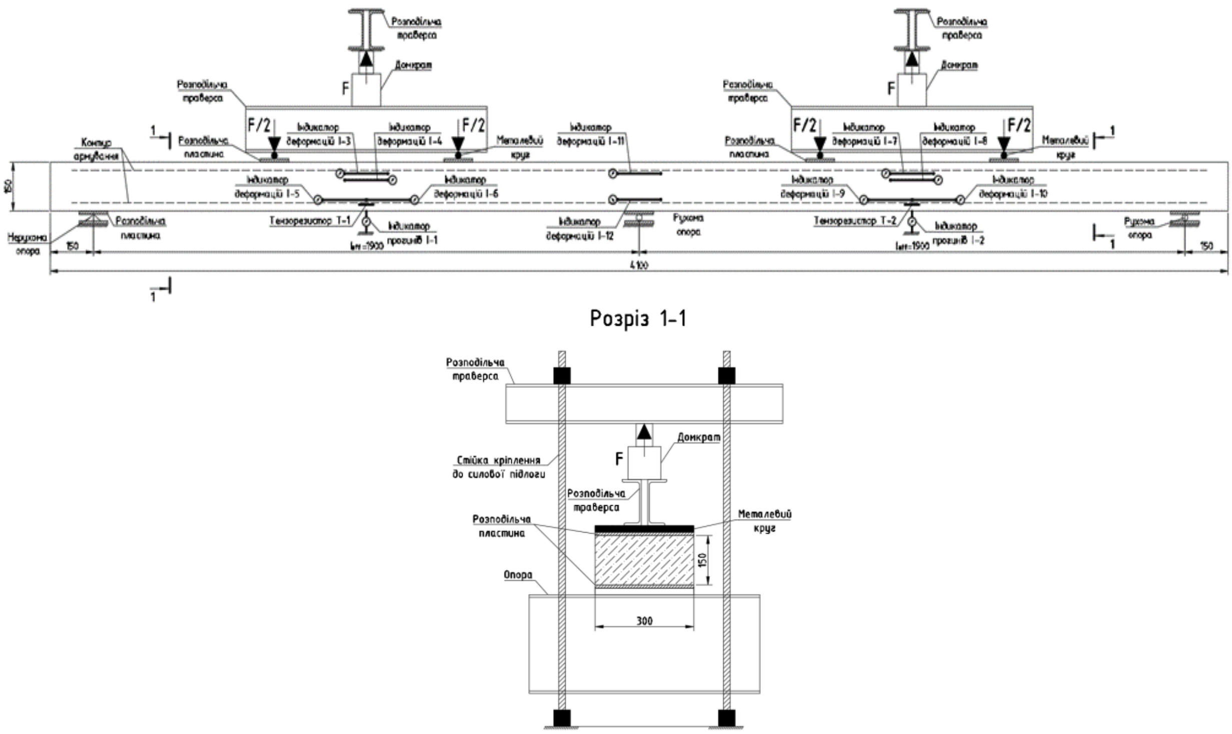

Fig. 9 Test scheme for a double-span beam B-2.1 series 2
Рис. 9 Схема випробування двопролітної балки Б-2.1 серії 2

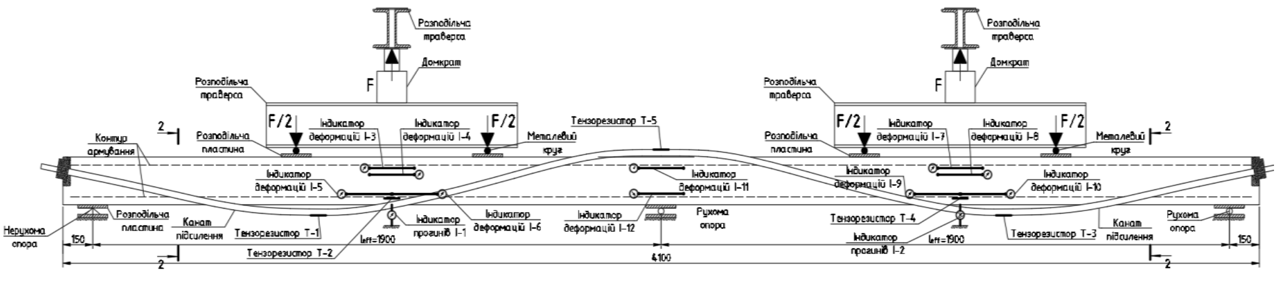

Fig. 10. Test scheme for reinforced double-span beam B-2.2 series 2
Рис. 10. Схема випробування підсиленої двопролітної балки Б-2.2 серії 2

PREPARATORY STAGE

The preparatory stage of the experimental study involves a complex of works on the manufacture of samples, installation of the reinforcement system and arrangement of the test rig. At this stage, the pouring of reinforced concrete beams, installation of anchor devices, fastening of pre-stressed ropes and preparation of control and measuring equipment for recording deflections, cracks and stresses in materials were carried out.

For series I and series II, the beams were made of concrete of class C20/25 with internal reinforcement Ø10 A500C. During the pouring process, special attention was paid to controlling the geometric dimensions, verticality of the reinforcing frame and uniformity of concrete compaction, which ensured the accuracy of the formation of structures and minimization of internal defects. The manufacturing process Fig. 11-12.

Fig. 11 Formwork and reinforcement arrangement before pouring experimental beams. Photo by: V.Vynokur
Рис. 11 Влаштування опалубки та армування перед заливкою експериментални балок. Автор фото: В. Винокур

Fig. 12 Single-span experimental beams. Photo by: V.Vynokur
Рис. 12 Однопролітні експериментальні балки Автор фото: В.Винокур

For the reinforced specimens, external prestressed cables Ø15.7 mm were used, fixed in anchor devices (see Fig. 13) with collets (see Fig. 14), which ensure reliable force transmission to the beam.

Fig. 13 Rope anchor. Photo by: V.Vynokur
Рис. 13 Анкер кріплення канату. Автор фото: В.Винокур

Fig. 14 Collet. Photo by: V.Vynokur
Рис. 14 Цанга. Автор фото: В.Винокур

Also at this stage, a test rig was assembled (see Fig. 15), which includes mechanisms for applying concentrated forces at points of maximum bending moment and a system for measuring deflections and cracks. The rig allows for precise loading and control over the experimental parameters, which is critically important for the representativeness of the results.

In addition, a specialized station was used to tension the ropes, ensuring accurate application and control of the calculated prestressing force. The configuration and main components of this station are shown in Fig. 16.

Fig. 15 Series 1 test rig. Photo by: V. Vynokur
Рис. 15 Випробувальна установка 1 серії. Автор фото: В.Винокур

Fig. 16 Rope tensioning station. Photo by: V.Vynokur
Рис. 16 Станція для натягу канатів. Автор фото: В. Винокур

The main measuring devices during the experiment are clock-type deflection indicators (see Fig. 17), which ensure accurate fixation of vertical displacements of beams at key points of the span.

In addition, to determine local stresses and deformations of the material in the zone of possible crack formation, clock-type strain indicators were used (see Fig. 18), which allow monitoring changes in the stress-strain state of reinforced concrete in real time. This makes it possible to more accurately assess the behavior of the material in critical zones and establish the stages of crack development.

Fig. 17 Deflection indicator. Photo by: V Vynokur.
Рис. 17 Індикатор прогинів. Автор фото: В. Винокур

Fig. 18. Strain indicator. Photo by: V.Vynokur
Рис. 18. Індикатор деформацій. Автор фото: В.Винокур

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Also used were strain measurement indicators of the type of extensometers (see Fig. 19), which provide high accuracy in determining the elongations or contractions of test specimens during loading. Extensometers allow direct recording of the change in the length of elements in the zone of greatest stresses, which allows for a detailed analysis of the distribution of deformations and an assessment of the effectiveness of structural reinforcement. The use of such devices is an important component of experimental studies, since they ensure the reliability of the data obtained on the stress-strain state of reinforced concrete elements.

To accurately determine the deformations in the internal reinforcement of reinforced concrete beams, the AID-4 device was used in the experiment (see Fig. 20). AID-4 is an automatic electronic strain gauge that operates on the basis of the strain gauge method, registering changes in the electrical resistance of strain gauges glued directly to the reinforcing bars.

Fig. 19 Extensometer. Photo by: V.Vynokur
Рис. 19 Екстензометр.
Автор фото: В. Винокур

Fig. 19 AID-4 device (Automatic electronic strain gauge). Photo by: V.Vynokur
Рис. 19 Прилад АИД-4 (Автоматичний електронний вимірювач деформацій).
Автор фото: В. Винокур

The AID-4 device was installed on the reinforcing bars in key areas of the span where maximum tensile deformations are expected.

CONCLUSIONS

The article presents a methodology for experimental research into the reinforcement of reinforced concrete beams using prestressed cables. The main objective of the research is to study the effectiveness of reinforcement, which allows to increase the bearing capacity, limit the development of cracks and reduce the deflections of such structures.

At the first stage of the research, beams of the first series will be tested. This series serves as a basis for the formation of initial experimental data and verification of the reliability of the adopted methodology. The results of the first series of tests will make it possible to specify the load parameters, measurement schemes and methods of fixing deformations, which will become the basis for improving the program of further experiments.

The second series, which involves testing double-span beams, can be specified or modified based on the results of the 1st series of tests. Such a phased approach ensures scientific consistency of the research, increases the accuracy of experimental observations and allows optimizing the parameters of future tests.

The preparatory work and the created experimental setup provide accurate control of loads and reliable fixation of the research results. The developed methodology forms a scientific basis for further testing, creating the prerequisites for developing practical recommendations for strengthening existing building structures.

Thus, the study contributes to the development of technologies for the restoration and reconstruction of reinforced concrete elements that have lost part of their load-bearing capacity, and is of great importance for increasing the reliability and safety of building infrastructure in the conditions of modern reconstruction.

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МЕТОДИКА ЕКСПЕРИМЕНТАЛЬНОГО ДОСЛІДЖЕННЯ ЗАЛІЗОБЕТОННИХ БАЛОК ПІДСИЛЕНИХ ЗА ДОПОМОГОЮ ПОСТНАПРУЖЕНИХ КАНАТІВ

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Анотація. У статті представлено методику проведення експериментальних досліджень підсилення залізобетонних балок із застосуванням попередньо напружених арматурних канатів. Розроблена методика базується на принципі підсилення елементів, що дозволяє підвищити їхню несучу здатність та тріщиностійкість без необхідності демонтажу або значного втручання в існуючу конструкцію.

Основна увага приділена технічним аспектам реалізації попереднього напруження канатів, зокрема способам їх закріплення, параметрам натягу, методам контролю напруженого стану. У роботі наведено послідовність проведення експерименту, що включає виготовлення серій дослідних зразків, схеми їх навантаження, методи вимірювання деформацій і фіксації розвитку тріщин.

На даному етапі дослідження виконано розроблення, виготовлення та монтаж випробувальної установки, призначеної для моделювання роботи підсилених залізобетонних елементів у різних режимах навантаження. Створена експериментальна база забезпечує можливість подальшого проведення серії випробувань, спрямованих на якісну та кількісну оцінку впливу попередньо напружених канатів на напружено-деформований стан балок та визначення ефективності запропонованої технології підсилення. Отримані у майбутньому результати стануть основою для формування практичних рекомендацій і вдосконалення методів розрахунку підсилених залізобетонних конструкцій.

Основною метою даної роботи є сприяння розвитку та впровадженню даної технології. Дослідження спрямоване на вдосконалення методики підсилення залізобетонних конструкцій і створення наукових передумов для оновлення нормативної бази, що забезпечить ефективне проєктування, підвищення надійності та довговічності будівельних об'єктів в Україні.

Ключові слова: підсилення, попереднє напруження, постнапруження, канати, методика

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