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# ANALYSIS AND GRAPHICAL REPRESENTATION OF STRESS-STRAIN STATE OF A BEAM DURING LABORATORY TESTING

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**Abstract.** For experimental testing in laboratory conditions, two series of beams were manufactured: reinforced concrete and with dispersed reinforced concrete. Each series contains 3 beam specimens, differing in the presence of fibers, three are reinforced concrete, three are steel fiber reinforced concrete. The dimensions of each beam are 2000x200x120mm. The stress-strain states of reinforced concrete and dispersed reinforced concrete beams were analyzed. Under the adopted loading scheme, all specimens from both series failed according to the same pattern: by inclined sections in the support zones. Steel fibers in the concrete restrain crack opening, so it is necessary to consider the behavior not only of the compressed zone of fiber-reinforced concrete but also of the tensile zone, unlike the calculation of reinforced concrete.

**Topicality.** The study of stress-strain states of beams forms the basis for understanding the behavior of flexural structures. In textbooks [1-3], we can observe design schemes of beams discussed in the course of strength of materials, along with their diagrams depicted in 2D format. In other sources, such as a textbook on reinforced concrete structures [4], it is also possible to observe stresses in reinforced concrete beams, which would be interesting to see not only in 2D but in 3D.

2D drawings can be effective for representing certain concepts or information, especially when the main focus is on details or surface characteristics. However, 3D drawings can provide a deeper understanding of spatial relationships and a more realistic context, which is particularly important when studying architectural, scientific, technical, or mathematical concepts.

In modern realities, a significant portion of education in Ukraine is conducted remotely, which means that students cannot visit laboratories and witness all processes firsthand, such as bending, compression, torsion, tension, and others. The use of 3D drawings allows adapting the approach to each student, providing a more effective way of knowledge transfer and facilitating their active involvement in the learning process.

In the textbook, in figure [2], trajectories of tensile principal stresses are shown, where having a clear visual representation of the internal force flow within the beam is crucial. In 3D illustrations, it is possible to better demonstrate trajectories of compressive principal stresses and understand the processes occurring within the beam.

In scientific articles [5-9], authors also more frequently illustrate material, particularly regarding stress-strain states, in a 2D format.

Therefore, the issue of analyzing and graphically representing the stress-strain state of a beam during laboratory testing is relevant. In this work, we aim to examine various stresses in beams presented in a 3D format for better understanding of the technical material through visualization.

For experimental testing in laboratory conditions, two series of beams were manufactured: reinforced concrete and with dispersed reinforced concrete. Concrete grade C20/25 was used for manufacturing. For reinforcement, two Ø12 bars were used as working reinforcement, two Ø8 bars for top reinforcement, Ø6 stirrups, with a concrete cover of 18 mm. In the support zone, the spacing of stirrups is half of that in the middle of the span. Each series contains 3 beam specimens, differing in the presence of fibers, three are reinforced concrete, and three are steel fiber-reinforced concrete. The concrete matrix was made from a concrete mix with a maximum aggregate size of 10 mm and a water-cement ratio of 0.5, allowing for proper mixing of the fiber into the mix for uniform distribution. The fiber reinforcement content is 1%, using fibers with hooked ends with a tensile strength of 1335 MPa, a fiber length of 50 mm, and a diameter of 1 mm. The dimensions of each beam are 2000x200x120mm. According to the testing scheme, the load is applied at a distance of

600mm from the edge, with supports located 50mm from the edge. Thus, the clear span length in the middle of the span is 800mm, and the two support zones for transverse bending are each 550mm long.

The beam tests were conducted according to the current standards [10-12]. A specialized force stand was used for testing, which was designed specifically for this research; its schematic is provided in Fig. 1. Loading is generated using a hydraulic jack, which presses against a distribution beam to transfer the load to the structure and create pure bending in the middle section of the beam. The upper rod of the jack is supported by an I-beam. To ensure all forces are balanced within the stand, the upper beam is connected to the lower support element. All forces generated by the force apparatus are balanced within the stand. During the tests, load values, deformations, and deflections were recorded, and the width of crack opening after crack initiation was also measured. Data were recorded immediately after each load step and after holding for 10-15 minutes. Dial gauges with a division of 0.01 mm were used for deformation measurements.

The tests were conducted by the staff of the Departments of of Construction Mechanics and Materials Resistance, with the involvement of graduate students and students in the laboratory of the Department of Materials Resistance of OSACEA.

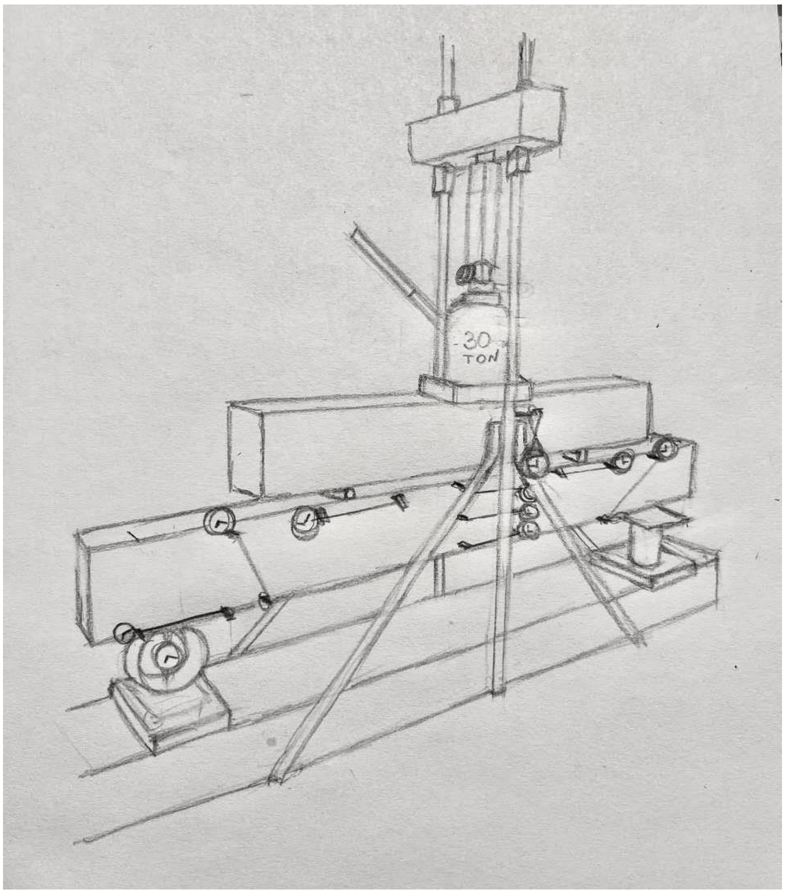


Fig. 1. Testing Stand

Let's consider the behavior of the beam at the beginning of loading. According to the theory of strength of materials, taking into account the known formulas, the general form of the diagrams of normal stresses in the pure and cross-sectional bending zones is the same, and at the beginning of loading, it has a standard appearance, meaning stresses change linearly along the height of the section and remain constant across its width. The maximum and minimum stresses are observed at the bottom and top edges of the section, respectively, while the neutral axis passes through the middle of the section's height.

The actual diagrams of normal stresses in the pure bending zone as the load increases, taking into account the material of the beams, are shown in Fig. 2. The first three are for the reinforced concrete beam, and the fourth and fifth are for the steel fiber-reinforced concrete. At the very beginning of loading, the diagram of normal stresses is linear, and the forces in the longitudinal reinforcement are also shown. The neutral axis passes through the centroid of the section. As the load increases in the reinforced concrete beams, cracks appear in the tension zone of the concrete, and the neutral axis shifts upwards, completely excluding the tensioned concrete zone from operation. The diagram of normal stresses in the compressed zone is nonlinear, with the compressive forces being absorbed by the working reinforcement. In the case of dispersed reinforced concrete beams, with the appearance of cracks, the neutral axis also shifts upwards, but the tensioned zone of the fiber concrete remains in operation. The stress diagram across the entire section height is nonlinear, and in the tensioned zone, the steel fiber impedes crack opening, meaning both the working reinforcement and the fiber concrete absorb tensile.

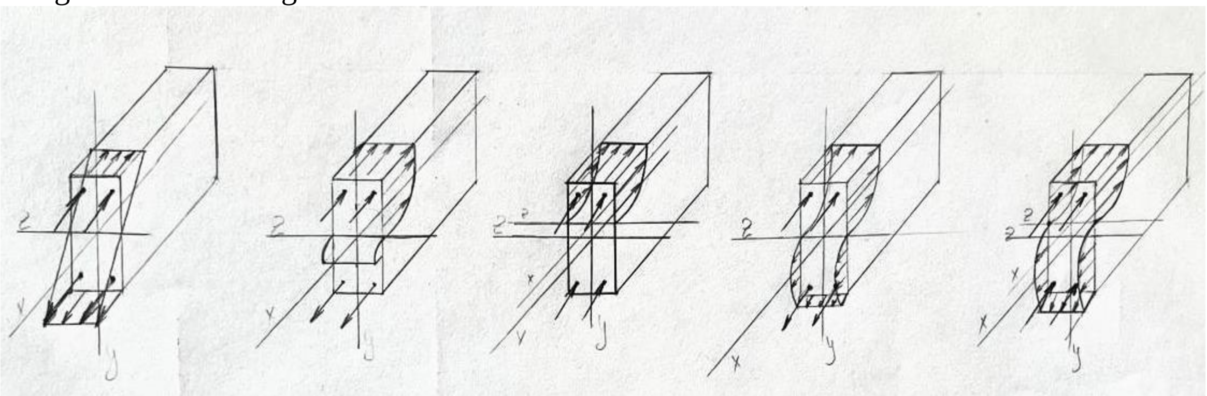

Fig. 2. The transformation of the normal stress diagrams in the pure bending zone with increasing load, 1-3 for the reinforced concrete beam, 4, 5 for the steel fiber-reinforced concrete

Under the adopted loading scheme, all specimens from both series failed according to the same pattern: by inclined sections in the support zones (Fig. 3).

Fig. 3. A crack along the left inclined section

Let's consider the behavior of the indicator installed in the zone of transverse bending along the tensile principal stresses, perpendicular to the inclined crack. The graph is plotted for a sample made of reinforced concrete, with a load-bearing capacity of 98 kN. Until the onset of crack initiation, the graph has an almost linear shape and sharply inclines to the right upon the appearance of the first crack. Crack initiation occurs at a load of 44.8 kN, with a relative linear deformation of $0{,}12 \cdot 10^{-4}$. After the onset of crack initiation, the graph becomes more gentle. Increasing the load leads to further deformation, the appearance of new cracks, and the opening of existing ones. The final value of relative deformation for this reinforced concrete beam is $1{,}22 \cdot 10^{-4}$.

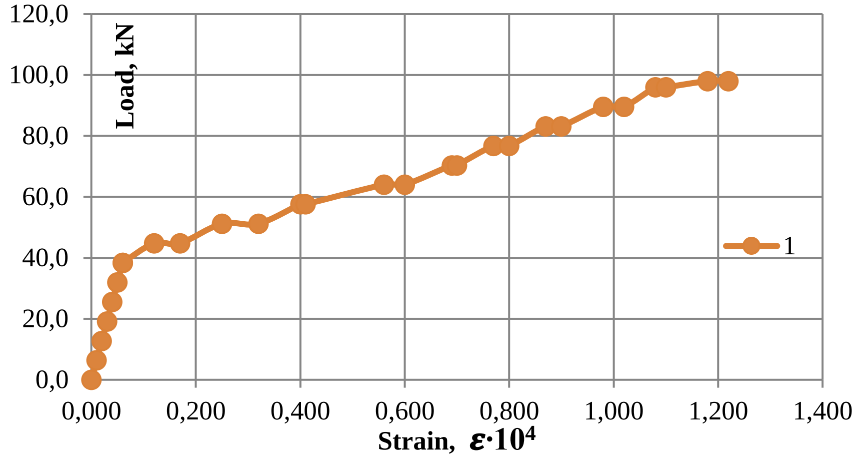


Fig. 4. The graph of the dependence of relative longitudinal deformation on the load

**Conclusions and results.** The stress-strain states of reinforced concrete and dispersed reinforced concrete beams were analyzed. Under the adopted loading scheme, all specimens from both series failed according to the same pattern: by inclined sections in the support zones. Steel fibers in the concrete restrain crack opening, so it is necessary to consider the behavior not only of the compressed zone of fiber-reinforced concrete but also of the tensile zone, unlike the calculation of reinforced concrete.

**References:**

1. Писаренко Г.С. та ін. Опір матеріалів: Підручник / Г.С. Писаренко, О.Л. Квітка. Е.С. Уманський; За ред. Г.С. Писаренка. 2-ге вид., допов. і переробл. К.: Вища шк., 2004. 654 с.

2. Шкельов, Л.Т. та ін. Опір матеріалів: Підручник для студентів вищих навчальних закладів / Л. Т. Шкельов, А. М. Станкевич, Д. В. Пошивач. К.: ЗАТ "Віпол", 2011. 456 с.

3. Шваб'юк В.І. Опір матеріалів: підручник для студ. інженерних спеціальностей вищих навчальних закладів / В. І. Шваб'юк. – К. : Знання, 2016. – 407 с.

4. Залізобетонні конструкції: будівлі, споруди та їх частини : Підручник / А.М. Павліков – Полтава, ПолтНТУ, 2017. – 284 с.

5. Борисюк О.П. Напружено-деформований стан залізобетонних балок підсилених під навантаженням сталефібробетоном і композитами при дії малоциклових навантажень// О.П. Борисюк, Ю.Ю. Зятюк // Ресурсоекономні матеріали, конструкції, будівлі та споруди: 36. наук. праць. – Рівне: НУВГП, 2016. – Вип. 33. – С. 298 - 303.

6. Zdanowicz, Ł.; Seręga, S.; Tekieli, M.; Kwiecień, A. Polymer Flexible Joint as a Repair Method of Concrete Elements: Flexural Testing and Numerical Analysis. Materials 2020, 13, 5732.

7. Radaikin Oleg, Sharafutdinov Linar. Reinforced concrete beams strengthened with steel fiber concrete. August 2020 IOP Conference Series Materials Science and Engineering 890(1):012045.

8. Xiuling Li, Jianan Qi, Yi Bao. Flexural behavior of fire-damaged concrete beams repaired with strain-hardening cementitious composite. June 2022. Engineering Structures 261(6):114305.

9. Сур'янінов Н.Г. Несуча здатність сталефібробетону з фіброю різного типу / М.Г. Сур'янінов, С.П. Неутов, І.Б. Корнеєва, Д.В. Величко // Науковий вісник ІФНТУНГ. Ів-Фр, 2020. Випуск 2(49). – С. 18 – 24.

10. Изделия строительные бетонные и железобетонные сборные. Методы испытаний нагружением. Правила оценки прочности, жесткости и трещиностойкости: ДСТУ Б В.2.6-7-95 (ГОСТ 8829-94). [Введен с 1995-11-16]. К.: Державний комітет України у справах містобудування і архітектури, 1997. IV, 30 с. (Національний стандарт України).

11. ДБН В.2.6-98:2009 Конструкції будинків і споруд. Бетонні та залізобетонні конструкції. Основні положення. Зі Зміною № 1. [Чинний від 01-06-2020]. Київ: ДП «УкрНДНЦ», 2009. 47 с. (Національний стандарт України).

12. ДСТУ-Н Б В.2.6-218:2016 Настанова з проектування та виготовлення конструкцій з дисперсноармованого бетону. [Чинний від 2017-04-01]. Київ, УкрНДНЦ, 2017. 32 с.