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IMPROVEMENT OF THE METHOD OF TEACHING CALCULATION OF STRENGTH LIMITS OF REINFORCED CONCRETE BEAMS

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Abstract: This article analyzes the shortcomings of current teaching methods for studying surface stress and deformation states in reinforced concrete beams, as well as the causes of their exposure to bending moments and shear forces during earthquakes. It then describes a proposed methodology based on problem-based learning, competency-based approaches, numerical modeling, and practical calculation examples. This approach aims to foster engineering thinking, integrate theoretical knowledge with practical applications, and develop students' independent calculation skills.
Keywords: seismic, Eurocode, reinforced concrete, structure, teaching methodology, construction, deformation, strength, concrete, reinforcement, engineering education, safety.

Introduction: Calculating reinforced concrete structures is an important part of civil engineering education. In particular, determining the strength limits of reinforced concrete beams is essential to developing the professional competencies of future engineers. Practical experience shows that students have difficulty mastering the limit state method, stress distribution, and reinforcement principles. Therefore, improving the teaching methodology for this subject is urgent. Ensuring the reliability of structures in seismically active areas is an important strategic task. Since much of the Republic of Uzbekistan is located in seismically active zones, strengthening reinforced concrete structures is considered an urgent issue [1]. At the same time, the vibration, bending, shear, and tensile forces acting on structural elements during an earthquake directly affect the structure's deformation capacity. Therefore, to increase the seismic resistance of reinforced concrete beams, a thorough analysis of their stress-strain state is necessary, as well as strengthening them using modern approaches [2-5].

Teaching students about the stress state, bending behavior, stress diagrams, and limit states of reinforced concrete beams helps develop their constructive thinking and computational skills, as well as their ability to work with regulatory documents. However, traditional classes limit computational processes to seemingly dry formulas. Therefore, it is necessary to update teaching methodologies and introduce interactive methods and graphic and computer modeling tools into the educational process [2].

Methodology: Research conducted in our country shows that, when implementing Eurocodes (European standards), seismically resistant structures can be designed based on the following principles:

- correct placement of energy-absorbing elements;
- control of elastic zones;
- increase the deformation capacity of the structure;
- prevention of complete collapse in case of overload.

The goal of this study is to improve the methodology used to teach the strength limits of reinforced concrete beams. It combined several methods, including theoretical calculations, the

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limit state method, and analysis of experimental data. It also monitored students' mastery through practical exercises. During the theoretical phase, students were guided through the step-by-step process of calculating the internal stresses and deformations of reinforced concrete beams. Visual instructions with examples and diagrams were provided for each formula, developing the students' conceptual understanding. The practical methodology was based on problem-based learning. Rather than using a ready-made algorithm, students had the opportunity to solve problems corresponding to real construction situations and master the problem. Additionally, through exercises analyzing experimental results, students learned to compare theoretical calculations with practical data, strengthening their engineering thinking. Considering the effective implementation of existing principles as a general stage, special attention should be given to the relevance of the teaching methodology. In fact, calculating the strength limits causes difficulties due to blind stages and blind formulas [2-3]. Therefore, the pedagogical process should focus on developing students' independent calculation skills through work with drawings, graphic analysis, and explanations using real structures as examples. During the study, the current curriculum and local and foreign literature were analyzed. The study employed problem-based learning, a competency-based approach, and practical calculation issues. Training was conducted using examples based on real engineering situations.

Experimental data analysis: Experimental studies conducted to determine the strength of reinforced concrete beams made it possible to evaluate their deformation behavior and the distribution of stresses within the cross-section. For the experimental program, reinforced concrete beams with cross-sectional dimensions of 15×25 cm and a length of 200 cm, reinforced with A400-grade steel bars, were fabricated. As the main longitudinal reinforcement, 2Ø16 A400 bars were placed in the tensile zone, while 2Ø10 A400 bars were provided in the compression zone. Ø5 Br-I steel bars were used as transverse reinforcement (stirrups). The experimental results demonstrated that the deformation values at the maximum bending moment were in good agreement with the theoretical calculations, with the observed discrepancies remaining within the limits specified by design standards. The stress distribution diagrams obtained from the experiments also showed close agreement with the results predicted by the theoretical model. Based on these findings, students were provided with the opportunity to apply the limit state method in practice through the analysis of experimental data. This approach not only reinforced theoretical knowledge but also contributed to the development of engineering thinking and independent calculation skills [6-10]. The experimental analysis demonstrated that the theoretical algorithms used to determine the strength limit states of reinforced concrete beams show a high level of agreement with the results obtained from practical testing. Therefore, the integration of experimental investigations and theoretical analysis within the educational process enables students to combine a scientifically grounded approach with practical application.

Results: Students instructed using the proposed methodology achieved high performance in solving independent structural calculation problems. The ability to carry out calculation procedures in a logical sequence and to apply diagrammatic methods and cross-sectional analysis was successfully developed. Reinforced concrete beams subjected to seismic actions experience the combined effects of bending moments and shear forces. As a result of these actions, the reinforcement undergoes tensile deformation, while the concrete is subjected to compression.The stress–strain relationship can be determined using the following formula:

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$$\sigma = \frac{M}{W} \qquad \varepsilon = \frac{\sigma}{E}$$

Here:
$\sigma -$ normal stress (MPa),
$M -$ bending moment (Nm),
$W -$ moment of resistance (m^3),
$E -$ modulus of elasticity of concrete (Pa).

It is essential to integrate theory and practice in engineering education. For instance, to evaluate the behavior of reinforced concrete beams under real operating conditions, laboratory experiments are conducted, enabling students to directly observe and compare the deformations and stress distributions measured in actual structural elements with those predicted by theoretical calculations. This approach significantly contributes to the development of students' structural and analytical thinking. As an example, the results of an experiment conducted on a cast reinforced concrete beam can be considered as follows:

Table 1:

Load level	Deformation (mm/m)
1	0.05
2	0.1
3	0.2

Discussion: A high degree of agreement was found between the results of the calculation of the strength limits of reinforced concrete beams and the results of the experimental studies and theoretical calculations. The similarity between the deformation and stress distribution diagrams obtained from the experiment and the theoretical model confirms the practical reliability of the calculation algorithms and the limit state method. Small differences identified through experimental analysis, such as changes in deformation and stress values at the maximum bending moment, can be explained by natural material variability and limitations in the test conditions. From a pedagogical point of view, working with experimental data fosters scientific thinking among students. By comparing experimental results with theoretical calculations, students understand not only formulas and algorithms, but also the actual behavior of structures. This approach strengthens problem-based learning in the teaching process as students learn to apply theoretical knowledge to practical situations. Additionally, comparative analysis increases the efficiency of training in accordance with the requirements of Eurocode and local regulatory documents. This approach strengthens the connection between theoretical and practical knowledge, engineering thinking, and independent calculation skills in students. At the same time, the obtained results demonstrate the practical significance of their application in teaching other reinforced concrete elements. Calculating the strength limits of reinforced concrete beams shows that, to make the structure more durable, the requirements of Eurocode 8 EN and relevant regulatory documents must be met [11-17]. The analyses and calculations presented in the report ensure the safety of structures in seismic environments. During an earthquake, buildings and structures, particularly reinforced concrete beams, experience the greatest loads and deformation stresses. A beam's seismic resistance is determined by its ability to absorb energy, deform, and maintain strength. Seismic resistance is the property of a structure that enables it to absorb and recover deformation energy without collapsing while maintaining its shape during an earthquake. There are several ways to increase the seismic resistance of reinforced concrete beams [5].

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Table 2:

№	Route name	Implementation measures
1.	**Improvement of the reinforcement system**	• Increase the amount of reinforcement in seismic zones. • Implement a two-directional reinforcement system. • Ensure the minimum thickness of the concrete cover for reinforcement (≥ 25 mm).
2.	Improvement of concrete quality	• Use high-strength concrete (B30 and above). • Increase the compressive strength of concrete by using polymer additives.
3.	Optimization of cross-section shape	• Designing the beam cross-section in I- or T-shape increases deformation capacity. • Ribbed or prestressed variants provide higher energy dissipation capacity.
4.	Use of additional strengthening elements	• Increase the amount of longitudinal reinforcement and the number of transverse stirrups. • Surface strengthening using carbon fiber (CFRP) or steel strips.

Conclusions and Recommendations: The proposed training methodology demonstrates the ability to combine scientific, theoretical, and practical knowledge when calculating reinforced concrete beams. Additionally, it is crucial to consistently monitor the quality of the concrete and reinforcement materials used in practice. The recommendations provided in this project are expected to significantly contribute to protecting structures from seismic hazards [5]. In our country, reinforced concrete beams are primarily designed using static analysis. However, implementation processes demonstrate that the Eurocode 8 EN approach enables a more thorough evaluation of seismic resistance through deformation analysis [4-8]. Based on the findings of these studies, the following measures are recommended for implementation in local engineering practice:

- Introducing Eurocode 8–based plasticity analysis methodologies into civil engineering practice and incorporating the principles of these methodologies into engineering education curricula;
- Developing methodological manuals focused on the application of energy-dissipating reinforcement materials;
- Improving methods for designing and producing high-density concrete compositions;
- Developing new national design standards grounded in the results of experimental investigations.

In conclusion, the seismic resistance of reinforced concrete beams can be increased by integrating structural, materials science, and design approaches. This improvement is not only a matter of material quality, but also a complex process involving the optimization of structural solutions, the enhancement of the reinforcement system, and the application of contemporary strengthening technologies. When teaching the process of calculating the strength limits of reinforced concrete beams incorporates modern pedagogical technologies, interactive methods, computer programs, and modular learning approaches, students will develop a deep theoretical

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understanding and solid practical skills in structural calculation. An improved methodology will help organize the educational process more effectively.

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