UDC 624.012 DOI: 10.31650/2786-6696-2023-6-54-61

ANALYSIS OF THE EFFECT OF UNEVEN DAMAGE OF REINFORCED CONCRETE BEAM USING THE FEMAP SOFTWARE PACKAGE

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Abstract. In most buildings and structures, reinforced concrete elements, which are operated with various damages and defects, are used. This article presents the results of theoretical studies of unevenly damaged reinforced concrete beams using the FEMAP software package. The occurrence of defects and damages leads to the danger of operation of buildings and structures, changes in the stress-strain state, and can lead to a decrease in the stiffness and bearing capacity of the structure. Defects and damages occur under the influence of the external environment, mechanical impacts, aggressive environment, and because of an explosion. The study aimed at analyzing the effects of the occurrence of uneven damage to reinforced concrete beams is of great practical importance in the future calculation of the residual bearing capacity and determination of the stress-strain state of a reinforced concrete element. Therefore, for theoretical studies, we use the finite element modeling of reinforced concrete elements in the FEMAP software package. The simulations were performed with different types of damage caused by wetting, alternating freezing, and thawing, and the stresses in concrete and reinforcement were analyzed using the finite element method (FEM), which is an effective numerical method for solving engineering problems. Based on the modeling results, the stresses were compared with the ultimate stresses, and the deformability of unevenly damaged reinforced concrete beams was determined. The results of the theoretical studies can be used in the future for practical experiments and are of practical importance in choosing the optimal method for calculating the residual bearing capacity of a reinforced concrete element. The importance of this study lies in its potential ability to improve the safety of building structures and reduce the risk of hazards during the operation of structures. The effectiveness of the FEM method, combined with these results, opens up new opportunities for engineers and researchers and can serve as a basis for improving the methods of calculating reinforced concrete elements under load using the latest finite element modeling technologies.

Keywords: damage, reinforced concrete beams, FEMAP, deformability.

Introduction. Determination of the residual load carrying capacity of reinforced concrete beams under various damages is an urgent task for the construction industry and is of great importance for design engineers. Damage to concrete can occur for various reasons, such as chemical attack, mechanical damage, improper operation, and other types of damage classified in [1]. This can lead to a decrease in the bearing capacity of beams and an increase in the risk of accidents, as well as to the occurrence of complex types of deformations of reinforced concrete elements that are not predictable in the design [2].

Research in this area is aimed at understanding the mechanisms of damage and its impact on the bearing capacity of reinforced concrete beams. The results of such studies can be used to set safety standards and develop recommendations. Accordingly, the assessment of the technical condition of reinforced concrete structures is the main diagnostic tool during operation, so there is a need to determine the bearing capacity and selecting the optimal reconstruction method.

This article discusses the stress analysis and deformability of reinforced concrete beams with non-uniform damage using the Femap software package based on NX Nastran.

Analysis of recent research and publications. The study of reinforced concrete beams with damage is a relevant area. When the compressed zone of concrete is damaged, the bearing capacity of the beam decreases, deformations and stresses change. Determination of the bearing capacity of reinforced concrete beams with damage to the compressed zone is investigated in [3].

The use of numerical analysis of the effect of damage to the compressed zone of concrete in a reinforced concrete beam provides important information for understanding the behavior and prediction of performance. Numerical methods are used to analyze the effect of concrete damage on the bearing capacity of beams and to study the mechanical characteristics of such structures.

Having considered the papers [4-5], which investigate the influence of cracks in the concrete compressed zone on the bearing capacity of reinforced concrete beams and their impact on the mechanical characteristics of structures. These articles are substantiated by numerical and experimental research methods. The main attention is paid to the analysis of the effect of cracks on the change in the bearing capacity of beams, in particular, various factors such as the depth and length of cracks, reinforcement, and material properties are taken into account. The results of the study of crack formation and failure of the concrete compressed zone contribute to a better understanding of this effect on the performance of reinforced concrete beams and its bearing capacity. In [6], typical flexural failure was observed in damaged beams. Bending cracks increased and propagated upward in the high moment region with increasing load. After reaching the yield strength, an upward shift of the neutral axis was observed, which led to concrete crushing in the compressed zone. Small inclined cracks of minor impact appeared throughout the span.

Klymenko E.V. [7] carried out the study of damaged reinforced concrete elements, the main direction of work was to create the basis for a methodology for determining the technical condition of damaged reinforced concrete structures and assessing the possibility of their further normal operation based on field tests. During the operation of reinforced concrete elements, there was a need to protect the bearing structures of the eastern stand of the stadium from atmospheric moisture. Prolonged soaking of reinforced concrete structures led to the destruction of the cover, corrosion of the longitudinal and transverse reinforcement. These damages necessitated the determination of the bearing capacity and deformed state.

The analysis of the stress-strain state and the determination of the residual bearing capacity of reinforced concrete elements using the FEMAP software package were performed in [8]. The basis for the research work was significant damage to reinforced concrete elements, errors in the manufacturing technology, non-compliance with the minimum cover, violations of the formwork geometry, and installation deviations. The objective of the study was to systematize the approach and factors that influence the decision-making process for strengthening a damaged reinforced concrete element, as well as to analyze the factors that influence the process of modeling an existing reinforced concrete element in order to determine the actual bearing capacity.

The most modern methods of modeling reinforced concrete structures using FEMAP and NASTRAN software are proposed by S. Kumar [9]. The author discusses methods of modeling, analysis and design of reinforced concrete elements and describes the process of creating models, determining loads, performing analysis and evaluating the bearing capacity and stability of reinforced concrete structures. The author also discusses in detail the use of software products for calculations and optimization of structures. The final results confirm that Femap and NASTRAN can be useful tools for modeling reinforced concrete structures and analyzing their behavior.

Among the publications, a broad overview of modeling and analysis of a reinforced concrete beam using the FEMAP software package is presented in [10]. In particular, the authors describe the methodology for constructing a geometric model, the correct input of material properties, and loading conditions. The process of analyzing a reinforced concrete beam with setting up boundary conditions and performing numerical analysis. Examples of modeling and analysis of reinforced concrete beams are presented to demonstrate the effectiveness of Femap and NASTRAN. The results indicate that these software products can be used to determine stresses and strains.

Research objective. Modeling of reinforced concrete beams with non-uniform damage under load in the Femap complex using the finite element method. Based on the modeling, to analyze stresses and strains.

The object of research is reinforced concrete bending structures of buildings and structures under conditions of long-term operation.

Materials and methods of research. For theoretical research and modeling, a normally reinforced concrete beam was designed, which will be used for experimental testing and comparison of the results with theoretical data. The geometric dimensions of the reinforced concrete beam are: length l=2100mm, height h=200mm, width b=100mm, distance between supports l_1=1900mm. The working reinforcement in the tensile zone of the beam is designed from rolled steel Ø16A500S (Young's modulus E=209200, Poisson's ratio = 0.29), upper reinforcement 2Ø6A240C, concrete of class C30/35 (Young's modulus E=34500, Poisson's ratio =0.21). The transverse reinforcement is made in the form of U-shaped clamps Ø6A240C with a pitch of 75 mm (Fig. 1).

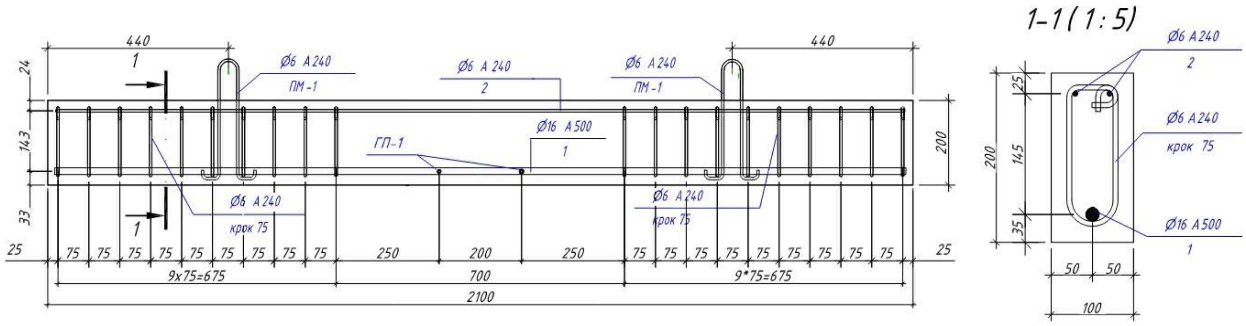

Fig. 1. General view of beam reinforcement

The reinforced concrete beam was designed to be installed on the test bench in such a way that its failure is expected in the zone of pure bending. To create the model and perform the calculations of the reinforced concrete beam, I used Femap, a widely used and modern software package for engineering analysis that facilitates the construction of finite element models.

The modeling starts with creating the necessary layers and entering the parameters of concrete and steel – Young's modulus, Poisson's ratio (Fig. 2).

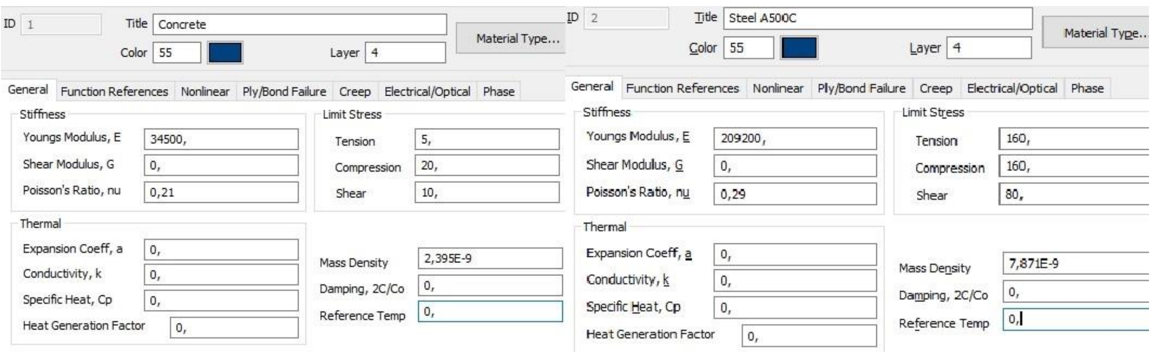

Fig. 2. Characteristics of reinforced concrete beam materials

The next step was to create a finite element mesh. To ensure the compatible operation of the reinforced concrete element, the modeling was performed with the condition that the edges and nodes of the concrete finite element mesh coincide. Formation of the element mesh included the creation of a plane from which finite elements were created using the "extrude" method along the entire length of the beam. To obtain accurate data, the finite element mesh was created from 10×10mm and 15×10mm cubes. The reinforcement was modeled using the BEAM element. After completing the mesh creation, all model nodes need to be merged using the "merge coincidence" command, which removes all unnecessary nodes and solves the problem of errors during the subsequent calculation of a damaged reinforced concrete beam.

After that, we create supports at a distance of 100 mm from its edge in the lower nodes of the beam along its entire width. On the one side – fixed support with a ban on movement along the TX, TY, TZ axes. The load with the value F (kN) is applied in 1/3 of the span (Fig. 3) to ensure a clean bending zone. The applied load F = 35.3 kN.

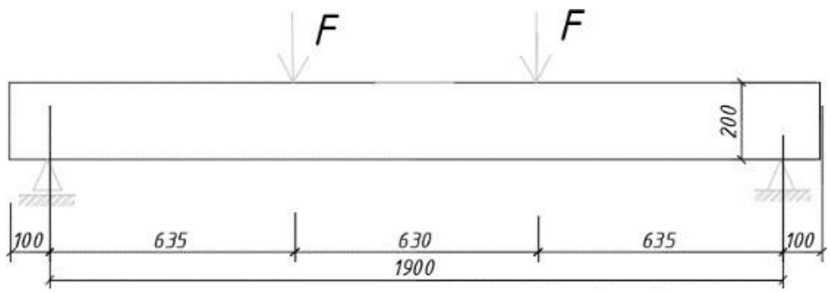

Fig. 3. Scheme of load application

For further study and analysis of a reinforced concrete beam with uneven damage, 6 variations of damage with variable values were selected and modeled (Fig. 4). The damage parameters are the following values:

– depth;
– is the damage angle α;
– is the value of the slice run delta a.

Damage may occur as a result of wetting or alternating wetting, freezing and thawing.

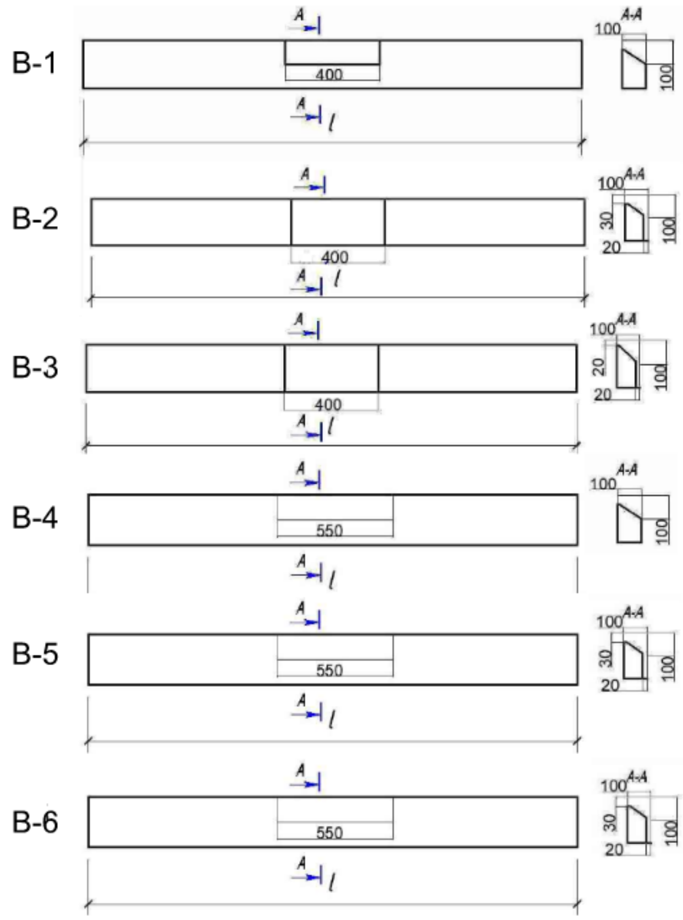

Fig. 4. Scheme of damage to a reinforced concrete beam

There are several ways to create a computational model fault in the FEMAP program [10], in this case, we chose to create it by deleting mesh elements. After deletion, the "merge coincidence" command must be used again to prevent errors. It is assumed that this damage may cause a change in the stress-strain state of the reinforced concrete element. As a result of modeling and static calculation using the Femap software, models and isofields of the reinforced concrete beam B-1 (Fig. 5, Fig. 6), displacements in the Y-axis (Fig. 7) and along the X-axis (Fig. 8) were obtained.

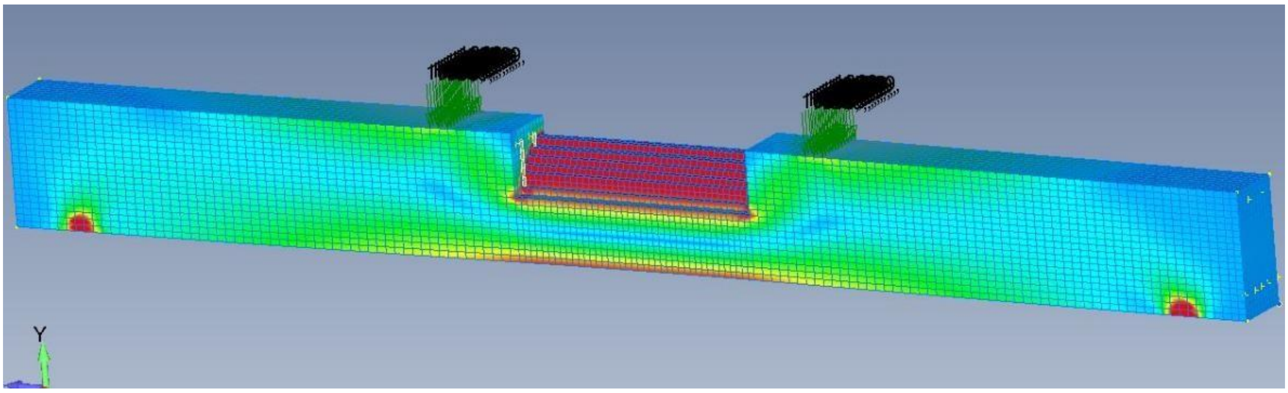

Fig. 5. General view of damage and stress isopleth of concrete of beam B-1

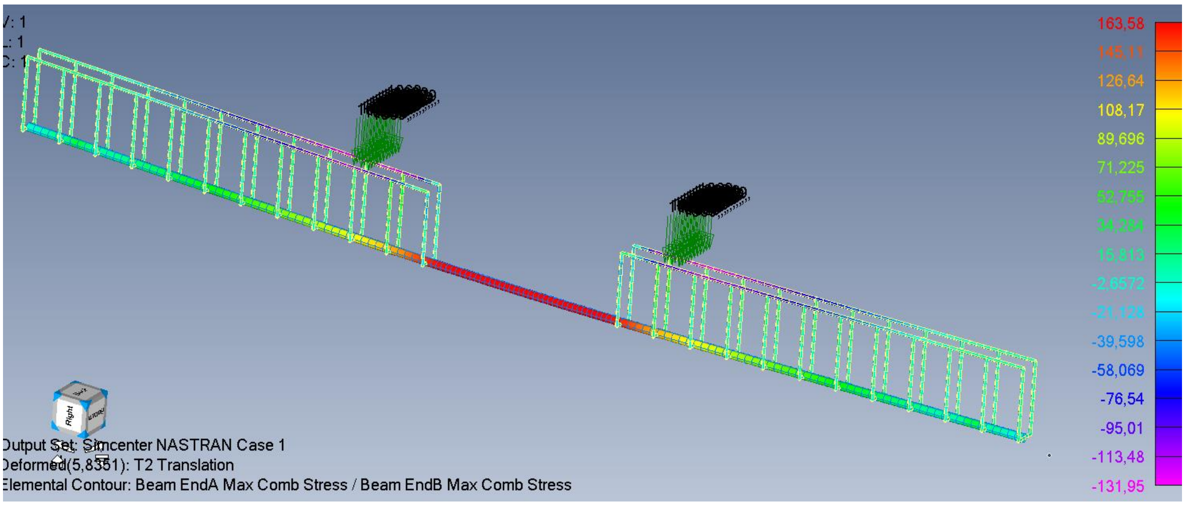

Fig. 6. Stress isofields in the reinforcement of beam B-1

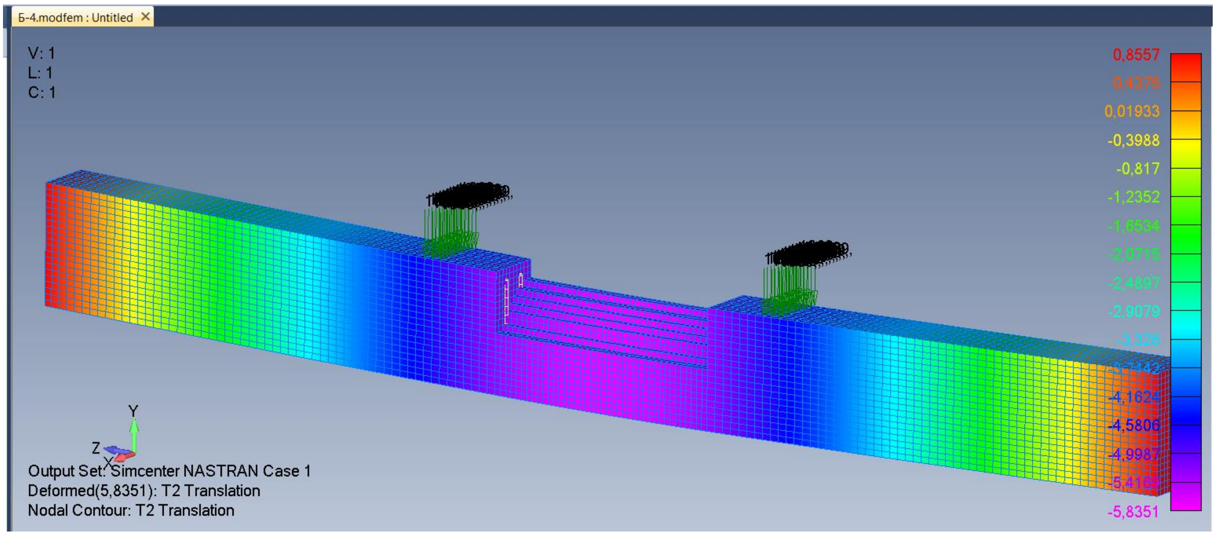

Fig. 7. Movement of the damaged beam B-1 along the Y-axis

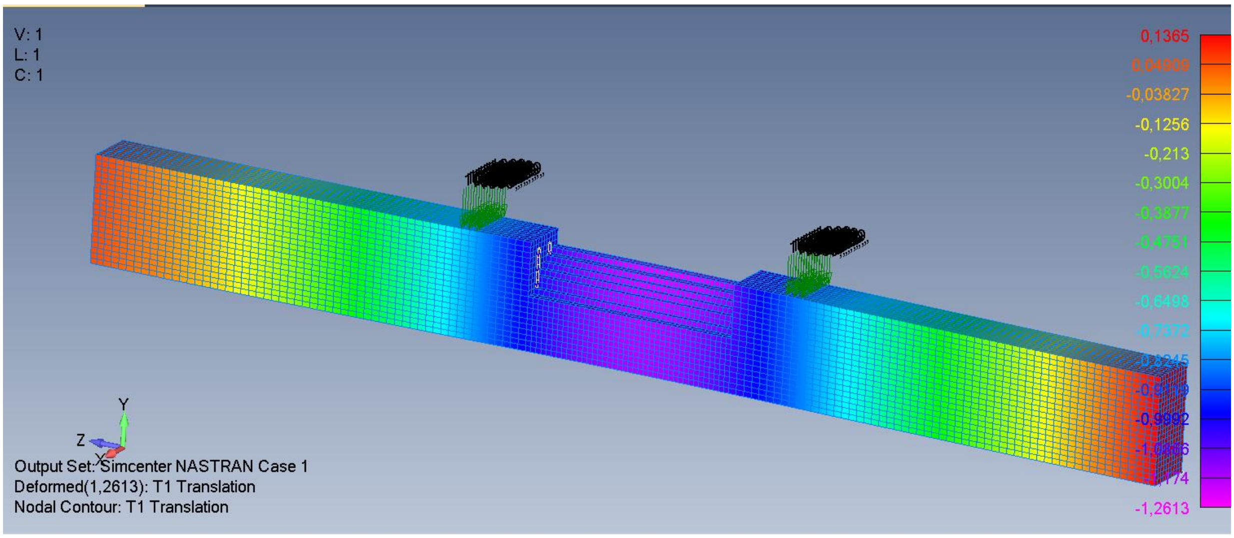

Fig. 8. Movement of the damaged beam B-1 along the X-axis

The theoretical results of unevenly damaged reinforced concrete beams are shown in Table 1. The analysis of these data allows us to understand which of the damage parameters can play a role in increasing the deformation under the load.

Table 1 – Summary indicators of damaged reinforced concrete beams

Title	Damage angle	Depth of damage	Length of the cut	Displace-ment along the Y-axis	Displacement in the X-axis	Max stress in concrete σc	Max stress in the reinforcement σs
B-1	45^{o}	100mm/ 100mm	400 mm	5.83mm	1.26mm	37.5 кN	135.58 mPa
B-2	30^{o}	-	400 mm	6.29mm	1.44mm	40.5кN	146.42 mPa
B-3	45^{o}	-	400 mm	7.06mm	2.03mm	45.36 kN	156.4 mPa
B-4	45^{o}	100mm/ 100mm	550 mm	6.41mm	1.4mm	41.23 кN	142.21 mPa
B-5	30^{o}	-	550 mm	6.97mm	1.6mm	44.52kN	158.3 mPa
B-6	45^{o}	-	550 mm	7.91mm	2.3mm	49.28 кN	167.7 mPa

Conclusions and Prospects for Further Research. Having analyzed the data obtained in the course of the work, the following conclusions can be drawn:

1. The use of finite element modeling of existing reinforced concrete elements will allow obtaining accurate results compared to analytical methods.
2. The theoretical study of unevenly damaged reinforced concrete beams in the FEMAP software environment allows us to study in detail the stresses in concrete and reinforcement under different variations of damage, to analyze displacements depending on the damage parameters. The results demonstrate the impact of the compressed zone on the reinforced concrete beam, as each centimeter of damage reduces the effective working height of the concrete, its bearing capacity, and changes the inclination of the neutral axis.
3. The modeling makes it possible to assess the impact of damage to elements and defects that occur in existing building elements under load.
4. We can conclude that this study is not complete and requires further refinement and comparison of theoretical results with experimental data.

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АНАЛІЗ ВПЛИВУ НЕРІВНОМІРНИХ ПОШКОДЖЕНЬ ЗАЛІЗОБЕТОННОЇ БАЛКИ З ВИКОРИСТАННЯМ ПРОГРАМНОГО КОМПЛЕКСУ FEMAP

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Анотація. У більшості будівель та споруд використовуються залізобетонні елементи, які експлуатуються з різними пошкодженнями та дефектами. У даній статті наведено результати теоретичних досліджень нерівномірно пошкоджених залізобетонних балок за допомогою програмного комплексу FEMAP. Виникнення дефектів та пошкоджень призводять до небезпеки експлуатації будівель і споруд, зміни напружено-деформованого стану, можуть призвести до зменшення жорсткості та несучої здатності конструкції. Дефекти та пошкодження виникають під впливом зовнішнього середовища, механічних впливів, агресивного середовища та внаслідок вибуху.

Дослідження спрямованні на аналіз впливів виникнення нерівномірних пошкоджень залізобетонних балок має велике практичне значення у майбутньому розрахунку залишкової несучої здатності та визначенні напружено-деформованого стану залізобетонного елементу. Тому для проведення теоретичних досліджень використовується моделювання залізобетонних елементів методом скінченних елементів у програмному комплексі FEMAP. Моделювання виконувалось із різними типами пошкоджень, які виникають внаслідок намокання, попереміннного заморожування-розморожування, а також проведено аналіз напруження в бетоні та арматурі, методом скінченних елементів (FEM), який є ефектним чисельним методом для вирішення інженерних задач. На основі результатів моделювання проведено порівняння напружень із граничними напруженнями, визначено деформативність нерівномірно пошкоджених залізобетонних балок. Результати теоретичних досліджень можуть використовуватись в подальшому для практичних дослідів та мають практичне значення при виборі оптимального методу розрахунку залишкової несучої здатності залізобетонного елементу. Важливість цього дослідження полягає в його потенційній здатності покращити безпеку будівельних конструкцій та зменшити ризик виникнення небезпеки під час експлуатації споруд. Дієвість методу FEM у поєднанні з даними результатами відкриває нові можливості для інженерів та дослідників і може служити основою для покращення методів розрахунку залізобетонних елементів при дії навантаження із використанням новітніх технологій моделювання методом скінченних елементів.

Ключові слова: пошкодження, залізобетонні балки, FEMAP, деформативність.

Стаття надійшла до редакції 11.09.2023