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THE INFLUENCE OF DAMAGE TO REINFORCED CONCRETE BEAM ON STRENGTH AND DEFORMABILITY: THE REVIEW

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In accordance with current conditions, it is necessary to change the aim of buildings and structures in which a large number of reinforced concrete elements that undergo complex stress-deformed states are used. The task for researchers is to determine the residual bearing capacity of the element with uneven damage, making it possible to choose the most optimal calculation option and select materials for optimization, preservation of strength, and durability. Also, a special role is played by the study of the impact of damage and defects, which cause a stressed – deformed state that cannot be predicted by calculation. Methods of determining the residual bearing capacity of reinforced concrete elements with various types of damage are considered. It also provides a detailed analysis of the most common defects and damages in reinforcement concrete structures, different types of corrosion.

Key words: reinforced concrete beam, damage, defects, bearing capacity, bi-axial bent, stress-strain state.

Introduction

Reinforced concrete structures account for a significant proportion of new construction. Many typical defects present in reinforced concrete structures affect the bearing capacity of the element. One of the most common causes of defects is using elements that do not meet the intended purpose. As a result, technological defects, cracks, and deformations due to force effects that exceed the standard value, corrosion damage, etc. The occurrence of deviations from the design solution for various reasons leads to work in a complex stress-strain state, particularly bi-axial compression, bi-axial and torsional bending. This all boils down to the need to determine the residual bearing capacity of such an element and make decisions on its restoration.

To analyze scientific sources that describe the impact of defects and damage to reinforced concrete elements on their strength and deformability.

Materials and methods

Reinforced concrete structures are exposed to various influences during their service life. The combination of an aggressive environment and underestimation of the importance of maintenance can lead to severe damage to reinforced concrete. The author, (Bonić et al., 2018), in his article classifies the causes of damage into the following groups:

Physical – due to alternate freezing and thawing of the structure, cracking caused by corrosion, and cracking due to cyclic loading.

Biological – refers to damage caused by tree roots and vegetation.

Chemical – carbonation, alkaline environment, crystallization.

The main factor in assessing the technical condition of reinforced concrete structures is the presence of damage and defects. According to a thorough analysis of studies of possible causes defects and damage it has been classified (Lobodanov et al., 2018), which are divided as follows (Fig. 1). Each object can also be classified by a list of parameters that will assess the technical condition, so it is challenging to identify identifiers that can be used to assess the condition of the building structure at the time of inspection according DSTU-N B V.1.2-18:2016.

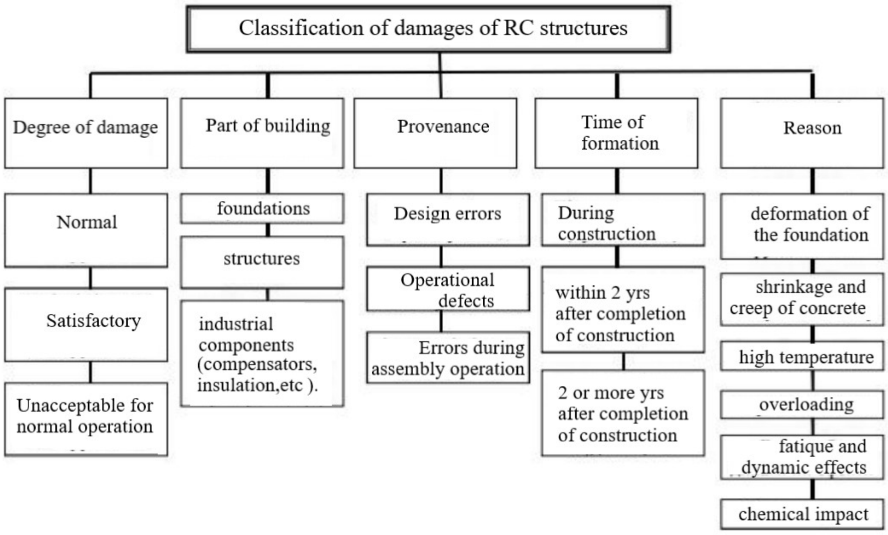


Fig. 1. Classification of structural damage and defects (Lobodanov et al., 2018)

A comparative description of defects and damages of reinforced concrete, metal, and steel-reinforced concrete beam structures is given in (Voskobiinyk et al., 2010). For example, schemes of possible damage to reinforced concrete beams (Fig. 2).

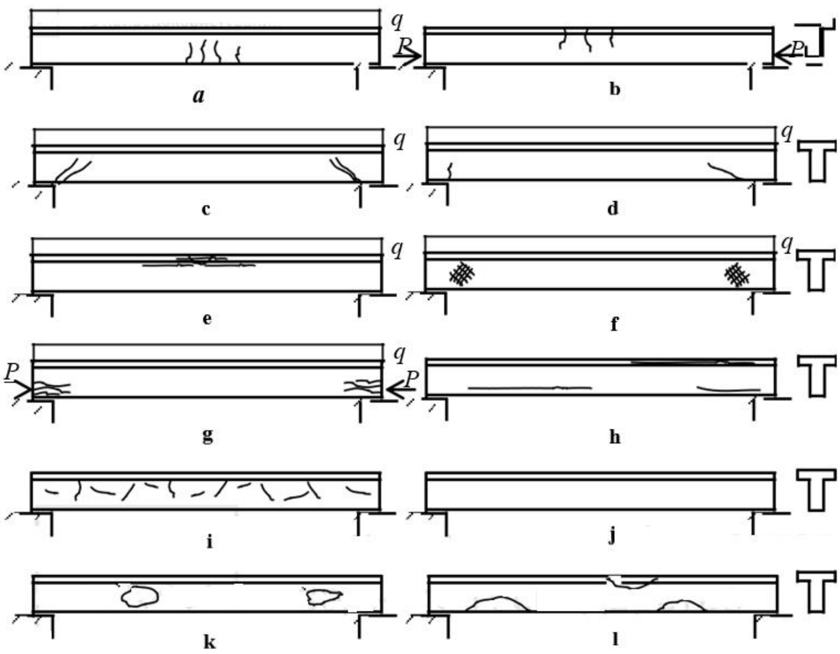


Fig. 2. Schemes of possible damage in reinforced concrete beams:
a, b – bending cracks, respectively, due to an external load; c – shear cracks; d – support cracks due to anchoring failure; e, f – concrete crushing and longitudinal cracks; g – longitudinal cracks due to prestressed reinforcement, h – longitudinal cracks due to corroded reinforcement; I – shrinkage of concrete; j – peeling due to aggressive impact; k – delamination of a concrete vise; l – delamination of the protective layer of concrete

Author characterized the causes of occurrence, proposed measures to eliminate defects, and classified the damage typical for reinforced concrete beams that may occur complex types of deformation that are not foreseen in the design (Voskobiinyk et al., 2011). Almost all bending or compression elements are subject to some degree of deformation, as they can occur not only from power loading. In particular, technological inaccuracies include the displacement of reinforcement from the design position in the manufacture of formwork (Fig. 3), which causes bi-axial bending (Voskobiinyk et al., 2011).

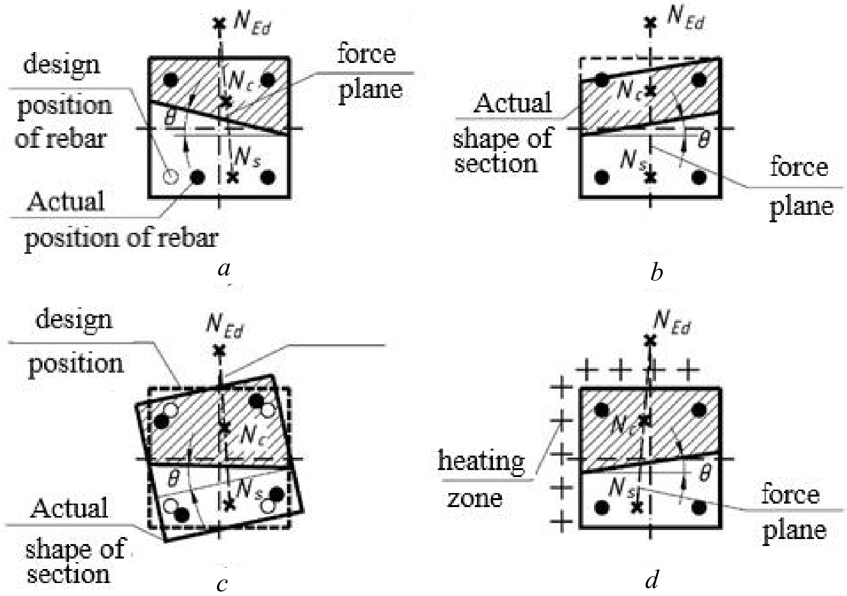
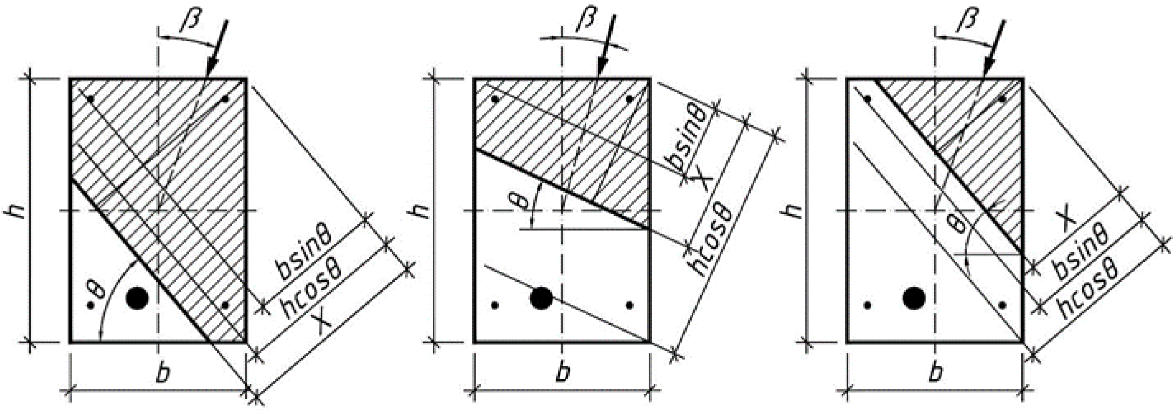


Fig. 3. Shapes of the concrete compressed area of concrete in bi-axial bent elements

The article division of factors into groups: exogenous and endogenous. Experimentally, a study of reinforced concrete beams undergoing bi-axial bending was carried out to investigate the strength of the section. A significant number of works have been devoted to the problem of determining the strength of sections (Pavlikov et al., 2011). Bi-axial bent reinforced concrete structures are designed for plane bending, simplifying calculations due to the complexity of performing calculations of complex types of deformations, which essentially leads to inaccurate calculation results, as a result of material overruns. The author presents the calculation of the strength of a section (Pavlikov et al., 2011), which is developed according to a simplified method (Pavlikov et al., 2019a) based on (Pavlikov et al., 2019b). The proposed calculation is based on a deformation model with a rectangular stress distribution. When studying the operation of elements in which bi-axial bending occurs (Voskobiinyk et al., 2011), one has to face difficulties in describing the stress-strain state of the sections. The main factor is that the concrete compressed area of concrete can acquire various geometric shapes that change the position of the neutral axis (Pavlikov et al., 2011), (Bonet. et al., 2006). Therefore, when analyzing the position of the neutral axis, it depends from the angle of inclination of the force plane to the central vertical plane of the element, the shape of the cross-section, the number of reinforcement bars and their location, etc. Experiments have shown that in bi-axial bending the most common shapes are triangular and trapezoidal (Fig. 4).

A method for determining the angle of inclination of the neutral axis in calculating the strength of a rectangular section of reinforced concrete elements under bi-axial bending in the case of a triangular zone was proposed in (Pavlikov et al., 2004). This article discusses the improvement of determining the bearing capacity of an element when the equations are based on the theorem of transferring a pair of forces to a parallel plane and identifies the shortcomings of the methodology based on the system of equilibrium equations at the limit state.



a *b* *c*

Fig. 4. Shapes of the compressed concrete area of the bi-axial bent elements:
a – pentagonal; b – trapezoidal; c – triangular

The determination of the shape of the compressed area in bi-axial bending and a comparative analysis of the modeling of bi-axial bent reinforced concrete beams with experimental data are given in the study (Pavlikov et al., 2019), where 15 samples of rectangular reinforced concrete beams (Fig. 5) were used and loaded at different angles of the applied external force to achieve bi-axial bending. Fig. 6 graphically shows the change in the slope of the neutral axis in the experimental samples.

As a result of numerical calculations by the finite element method using a software package, stress, and strain distribution graphs were obtained. It was determined that the finite element method in the software package allows for taking into account the peculiarities of reducing the bearing capacity of the studied element.

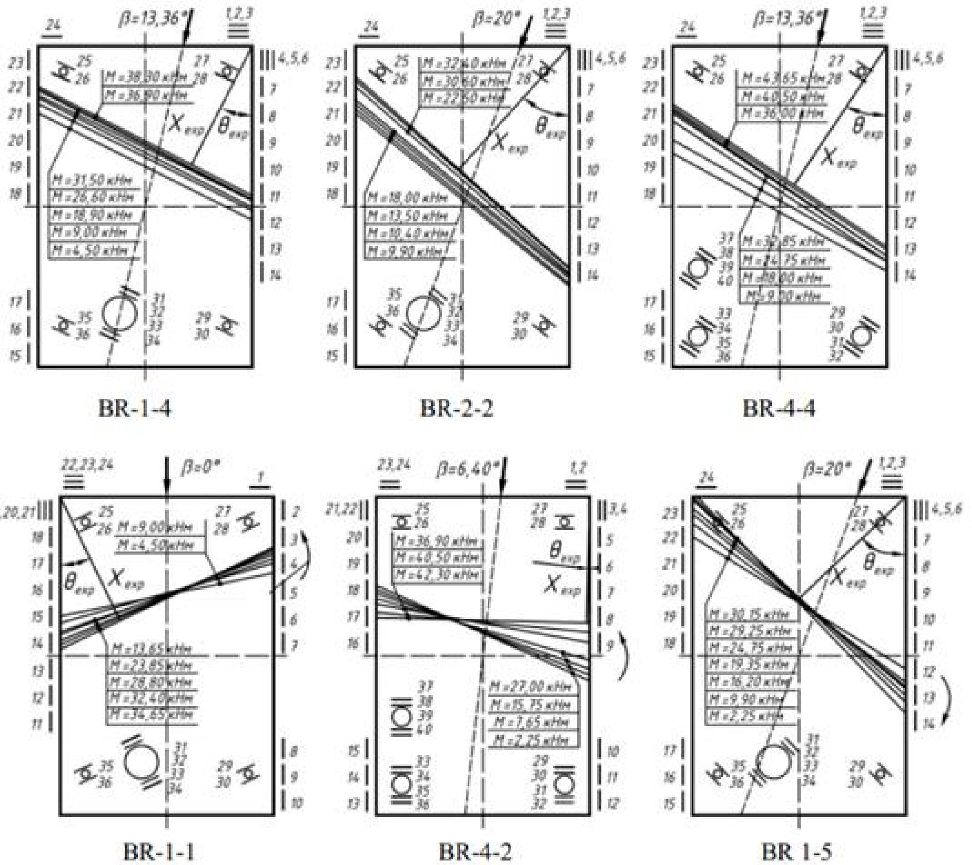


Fig. 5. Change in the neutral axis angle under load

According to design experience, it is known that reinforcement at the intersection with cracks can corrode. In article (Zhang et al.,2019), discusses the effect of top-casting-induced defects on the corrosion development of compressive bars in reinforced concrete beams exposed to a chloride environment, under sustained loading. Also noted that before the appearance of cracks, corrosion mainly occurred at the bottom part of top-casting bar according to the casting direction due to the fact that defects at the steel–concrete interface under a horizontal bar promoted anodic behavior.

The study (Vidal et al., 2004) investigated the effects of corrosion on the crack widths and reinforcement losses of rc concrete beams stored in chloride environment. The analysis of the cracking process showed that crack initiation depends on the cover/diameter ratio and bar diameter, while crack propagation is unaffected by the cover/diameter ratio and bar diameter. The influence of corrosion damage on the change in the strength characteristics of reinforcing steel under static loads was studied in article (Khmil et al., 2009). During the experiment corrosion damage on the samples was obtained by holding them in a 3 % sodium chloride solution. As a result, it was found that corrosion damage does not significantly affect the strength characteristics. However, this phenomenon should not be allowed under seismic and dynamic impacts. The topic of the residual strength of corrosion damage is also covered by the author (Abul et al., 2007). In this study, an attempt has been made to predict the residual flexural strength of a corroded beam through the use of conventional flexural formula by taking into account the loss of metal due to corrosion and an applicable correction factor to account for the loss of bond. Analyzing foreign sources, many investigations of reinforced concrete elements have been conducted. In the article (Monti et al., 2006), the author presented a method for determining the bearing capacity of a reinforced concrete column subjected to bi-axial bending under load. A slight deviation from the exact value was found in determining the bearing capacity, and a significant advantage of using elementary equations was also noted. The importance of the study is confirmed in (Furlong et al., 2004), in particular, a comparison of the numerical theoretical method with the use of software systems for calculating and analyzing the impact of loading and new equations to improve the accuracy of strength calculation.

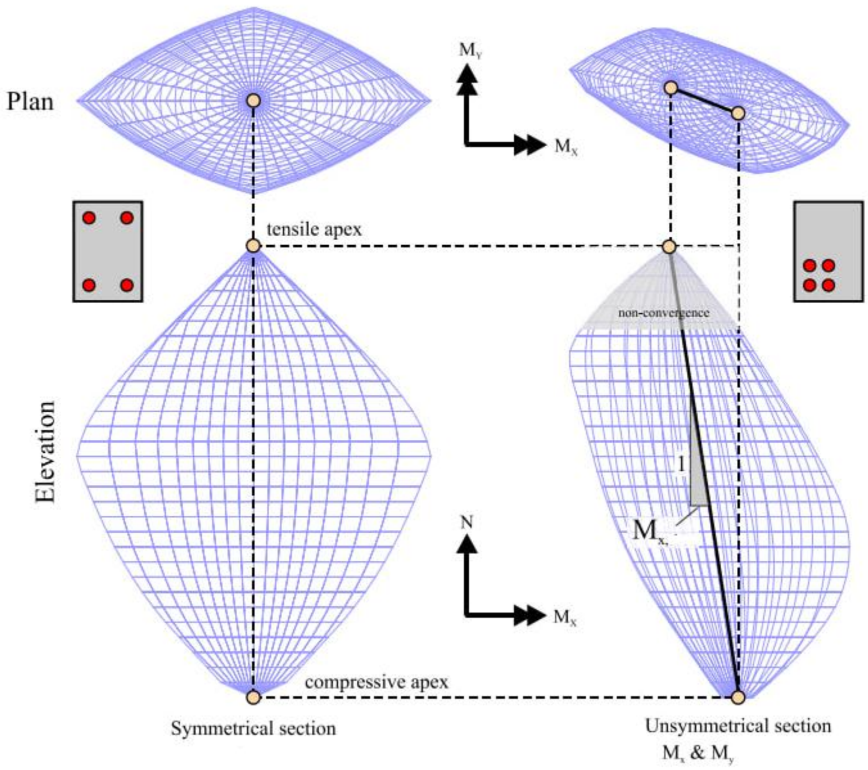


Fig. 6. Determination of the effect of cross-sectional asymmetry

In (Vassilis et al., 2012), a methodology containing various new algorithmic procedures for changing geometry was presented for analysis. Through validation tests, comparison with existing literature, and benchmark tests, a methodology for the analysis of arbitrary cross-sections was proposed, including geometry and material definition, integration scheme, limit state derivation, and solution strategies, limited to an object-oriented implementation, which shows a very satisfactory result in terms of performance and speed of determination. Various extensions of this method are currently being investigated, in particular in the area of assessment of reinforced concrete elements under load. In constructing a three-dimensional fracture surface, the occurrence of bi-axial bending in asymmetric areas is depicted (Fig. 6).

The proposed methodology for analyzing arbitrary sections, consisting of determining the geometry of the material and integrating schemes has the following novelty: a self-correcting centroid for asymmetric sections and derivation of limit state criteria. Regulatory documents (distinguish four technical states. In article (Klymenko et al., 2012) author proposes a system that will determine certain parameters of building structures and compare them with permissible values, assess the consequences of the structure's transition to another state, and determine the residual bearing capacity.

Calculations are performed in one or two stages. In the first stage, the sections' bearing capacity, the crack opening width, and the deflections of the structure are determined. If the reinforced concrete structures are not damaged, they can be calculated according to the regulatory codes that existed during the facility's design. The residual bearing capacity of damaged reinforced concrete elements was determined in (Klymenko et al., 2014). The paper analyses different types of damage to I-beams. The results of experimental studies of the stress-strain state of reinforced concrete beams of rectangular cross-sections with damage in the compressed area were modeled using the LIRA software (Klymenko et al., 2019). It is relevant to conduct theoretical and experimental studies at the LIRA Research Software to determine the actual work and residual bearing capacity. The authors investigated the residual bearing capacity of reinforced concrete beams; the load was applied as a concentrated force, and 15 different test beams were created according to the plan. Fig. 7 shows the geometric characteristics of the damage to the samples. The failure criterion was the achievement of one of the following limit states: yield stress in the longitudinal or transverse reinforcement; achievement of the ultimate stress in a significant group of finite elements of compressed concrete at the point of sample support or above the top of a shear crack; achievement of extreme displacement values.

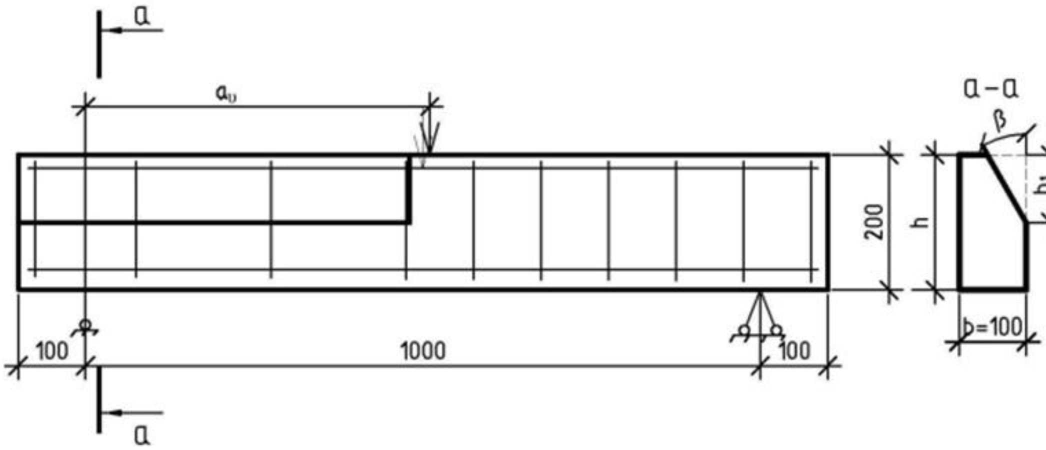


Fig. 7. Geometric characteristics of the prototypes (Klymenko et al., 2019)

When obtaining theoretical data, the results of the residual bearing capacity in comparison with the experiment varied from 3.23 % to 21.46 %.

Results and discussions

The result of article is to find out various studies and experiments related to the stress and strain state, residual bearing capacity, and damage of reinforced concrete elements under loads. Also emphasized the importance of finding accurate experimental and theoretical values, improving calculation methods, and conducting further research on the development of new methods for assessing the stress and strain of reinforced concrete elements under different conditions of loading. The review article also discussed that it is necessary to analyze scientific sources that describe the impact of defects and damage under load and require improved methods, developing new techniques for monitoring the condition of reinforced concrete structures over time under load. The results of the obtaining theoretical data in comparison with the experimental are discussed and highlithed.

Conclusions

Investigating the types of damage and defects, the stress-strain state, and the bearing capacity of reinforced concrete elements, we conclude that the most important factors are finding accurate experimental and theoretical values, determining the residual bearing capacity of unevenly damaged reinforced concrete elements, improving calculation methods, analyzing theoretical values by the finite element method in several calculation programs to select the optimal model, It is also essential to conduct further research on the development of new methods for assessing the stress and strain of reinforced concrete elements under different conditions of loading, as well as determining the effect of time and environment on their bearing capacity and longevity.

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ОГЛЯД ВПЛИВУ ПОШКОДЖЕНЬ ЗАЛІЗОБЕТОННИХ БАЛОК НА МІЦНІСТЬ ТА ДЕФОРМАТИВНІСТЬ

Відповідно до сучасних умов, доводиться змінювати призначення будівель і споруд, у яких експлуатується велика кількість залізобетонних елементів, що зазнають складних напружено-деформованих станів. Вони зазнають різних впливів навколишнього середовища, нерівномірного завантаження, пошкодження та дефектів, внаслідок цього їх складний напружено-деформований стан відрізняється. Пошкодження та дефекти слід класифікувати за різними характеристиками та критеріями, оскільки питання пошкоджень є досить складним. Задачею для дослідників є визначення залишкової несучої здатності елементу з нерівномірними пошкодженнями, які б надали змогу вибрати найбільш оптимальний варіант розрахунку, підібрати з вищою точністю матеріали для підсилення, збереження міцності та довговічності конструкції. Також особливу роль займає дослідження впливу пошкоджень і дефектів, які викликають напружено-деформований стан, непередбачуваний проєктом. Досліджуючи роботу залізобетонних елементів, доводиться стикатись із труднощами під час опису напружено-деформованого стану їх перерізів, тому часто приводять до спрощень, що спричиняє спотворення дійсного стану роботи конструкції і зменшує достовірність отриманих даних у ході експерименту. Зазвичай такі відхилення виникають за різних видів зовнішніх впливів на залізобетонні елементи, що мають вплив на фактори під час розрахунку на міцність та визначення методології для виконання дослідження. Проведено опис досліджень основних типів дефектів та пошкоджень, що виникають у залізобетонних елементах. Розглянуто методи визначення залишкової несучої здатності залізобетонних елементів з різними типами пошкодження. Проводиться аналіз основних дефектів та пошкоджень, дія яких призводить до зміни характеристик міцності та можливої зміни складного напружено-деформованого стану.

Ключові слова: залізобетонна балка, пошкодження, дефекти, несуча здатність, косий згин, напружено-деформований стан.