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Influence analysis of the main types of defects and damages on bearing capacity in reinforced concrete elements and their research methods

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Abstract
In current economic trends, changes in construction using are required. It usually leads to changes in value and type of the working load on building structures, with the requirement to rate the technical state and replace or strengthen the elements. An important aspect of determining the residual bearing capacity of damaged bending reinforced concrete elements is the research concerning the influence of difference defects and damages on the change of strength and deformability. In the article main types of damages and defects, methods of studies of damaged reinforced concrete elements and the expediency of usage of this elements are described. However, most methods are suitable only for certain defects and damages due to the large complexity of calculations and the consideration of multifactoriality. Significant complexity of a single method for calculating damaged elements depends on the possible changing stress strain state of an element in combination with certain defects and damages, the presence of a non-complete separation where during loading or alteration of the damaged element the fractions become included in the work, reinforced concrete is the composite material which carrying complexity in calculating the joint work of its components.

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1. Introduction

A significant number of buildings and constructions is built with the use of reinforced concrete constructions. Some of them are exploited in a damaged condition. Defects and damage occur at various stages, for example the manufacture of an element with incorrect placement of internal reinforcement which leads to a change in the stress-strain state of an element that differs from the design decision; damage to the element during transportation and installation; mechanical shaking of the protective layer or more inactive damages; use of elements what are not suitable for the intended purpose, or significant changes in the load on elements. A special case is the action of an aggressive environment and others; damage to an element in natural phenomena (landslides, earthquakes, etc.); damage to the element with explosions and shock effects. All these factors make it necessary to determine the residual bearing capacity of the damaged element to establish their actual bearing capacity and the subsequent development of the reconstruction project.

2. Aims

Since the study of damaged elements is an urgent topic, the main aim is the analysis of the existing research on the influence damages and defects of reinforced concrete elements on their strength and deformability, and researching methods for them.

3. Results and discussion

The question of classification of damages of reinforced concrete (RC) structures is inadequately described in the different norms and research works. Therefore, one of them has been approved by the technical committee of DCC-104 RILEM (International Union of Experts and Laboratory of

Testing of Building Materials, Systems and Structures) in 1991, where has been classifying damages in concrete constructions (Rilem Technical Committees: Damage classification of concrete structures), to which the authors refer to in the following work (Klymenko, 2013a).

When describe the issue of residual bearing capacity of flexural reinforced concrete elements in damaging, an important place is the classification of damage and defects. The most widespread ones in terms of the loss of the concrete cover according to Malganov (1990) and Voskobinik (2010) are shaving of the nominal cover of concrete which occurs when: there is mechanical damage during transportation and operation; corrosion of reinforcement; influence of the fire and the detachment of concrete brushes occurring during fire, during pressure of tumors, e.g., salt or ice; or soaked in case of violation of the operation's rules.

In the study of the influence of damage to the strength and decorative properties of bending reinforced concrete elements, the author (Klymenko, 2012) emphasizes the failure to take into account the Ukrainian codes (DBN V.2.6-98: 2009.; Normative documents on issues of inspection, certification, safe and reliable operation of industrial buildings and structures 1997; GOST 20911-89, 1989) the possibility of determining the residual bearing capacity, which necessitates the formation of a problem of implementation, proposals regarding solutions, use of available work, implementation of decisions, formation of the final calculation and methodology.

The main problems connected with the implementation of the method of determining the surplus bearing capacity (Klymenko, 2012) are:

- in the formation of partial destruction, since the front of destruction is not parallel to the axes of symmetry, but the transition from a flat bend to skew;
- the emergence of a complex stress-strain state leads to the calculation of a simplified scheme, based on the construction to flat bend in different planes;
- necessary experimental and theoretical research of the damaged elements working on bending and development of an experimentally tested method of calculating the strength of these elements.

Suggestions for a solution and workout for solution are as follows:

- conducting of experimental research and development of calculation methods of elements of reinforced concrete constructions, which work on a biaxial bend; introduction into the theory of calculations of strength of reinforced concrete elements of a nonlinear deformation model with use of complete diagrams of deformation of concrete and reinforcement;
- introduction of a simplified deformation model without loss of accuracy of calculations, for their practical application by engineers, and scientists;
- the use of the technique (Stepova, 2011) allows to obtain the parameters necessary for the calculation of the non-destructive method during the design examination and in the process of operation, and to predict the loss of cross-sectional area of the armature in a crack under a particular operating mode;
- analysis of the numerical values of the creep deformation allowing to conclude that rapidly increasing deformations can form a significant part of the deformations of sufficiency;
- the use of calculation without iterative methods simplifies the method of determining the strength of reinforced concrete slabs working on slanting bends. This issue is considered in the work of Pavlikov AM, Boyko, O. (Pavlikov, 2011).

In Klymenko's study (2012), the stress-strain state of beam reinforced concrete elements was simulated using PC "Lear 9.6", on the basis of isotopes, using a piecewise linear dependence, which can be applied to any material, both primary and secondary. According to the author, a consistent analysis of voltage isopolls in materials of real construction allows to reliably estimate the influence of constructive factors on the bearing capacity, to predict the nature of further deformation and physical destruction.

To determine the residual bearing capacity of the damaged bended reinforced concrete elements was carried out on the T-beams in the work (Klymenko, 2014). The possibility of realization of various types of imposition in the role of variation factors during modeling in PC "Lira 9.4" is analyzed:

- the damaged part of the flange, expressed by the ratio (beff1 / beff2), where beff1 - the magnitude of the damage; beff2 - size of the flange' nights;
- the damage depth a1, expressed in terms of the ratio of the depth of damage to the flange to the thickness of the shelf (a1 / hf 1);
- the angle of the damage β, expressed due to the ratio of the damage to the angle of inclination of the shelf, equal to 90o.

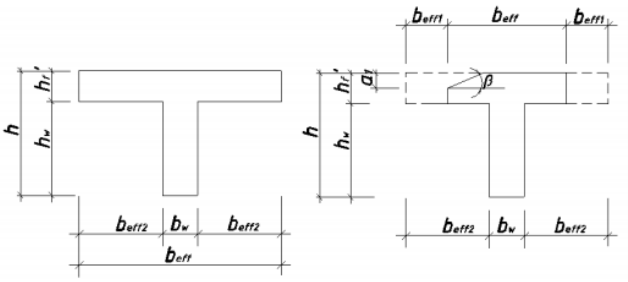

Fig. 1. Cross section of control beam and beam with damaged flange (Klymenko, 2013b)

As it is shown in the conclusion of the paper, the simulation of damages of bended reinforced concrete elements in software complexes based on the finite element method is a way to determine the residual bearing capacity, but this is a rather laborious process.

In (Klymenko, 2013b), the influence of damage factors of T-beams on the magnitude of their destructive load is analyzed. In the process of analyzing the experimental data obtained through a method by Voznesensky (1981), that is the removal of insignificant coefficients of the regression equations, an adequate mathematical model has been obtained that has sufficient information and by means of which it is possible to estimate the influence of the investigated factors on the initial parameters of the beams, the geometric interpretation that is presented in (Klymenko, 2013b) where FULS is an external impedance at which the beam is destroyed.

The most common defect is corrosion of reinforcement. Due to corrosion, its volume increases, which leads to a violation of the integrity of the nominal cover (Verb, 2002). The process runs in a hidden form and leads to a decrease in load carrying capacity. In reinforced concrete structures, electrochemical corrosion is often encountered. In the conditions of operation of most of the structures between the two metals that are in contact there is an electrical interaction. In many cases, low-carbon steel is relatively low-alloy anode. It should be noted that very low-carbon steel has a non-uniform structure, which can be a factor contributing to corrosion.

The rate of corrosion depends on the factors associated with the amount of oxygen and the permeability of concrete:

- from contact with steel and ion permeability to the water phase of concrete which depends on the composition and amount of water in the concrete;
- the presence of anode and cathode plots on the metal, which is observed when exposed to any part of the armature;
- the presence of oxygen which promotes reactions.

Potential cause of corrosion may be the presence of chlorides in porous concrete. The corrosion of the fittings leads to a decrease in the area of its section and, as a result, the fall of the bearing capacity of the structural element, structures.

The influence of the aggressive environment on the bending reinforced concrete elements is considered in article (Khmil, 2009) and the following aspects of influence were noticed:

- destruction of reinforced concrete beams in the medium of sulfuric acid occurs due to corrosion of concrete and in some samples, in combination with corrosion of reinforcement. Corrosion of concrete causes chemical reactions of acid with components of a cement stone, which contain calcium. In this case, corrosion proceeds gradually from the outer layers of concrete into the experimental samples with the formation of a contact layer.
- corrosion processes reduce the cross-sectional dimension of beams in time by linear dependence. Reducing the cross section of compressed concrete, as well as the working height of the section in general, causes an increase in stresses in concrete and reinforcement. The collapse of the beams occurs when the stresses in the reinforcement of the yield strength and the subsequent fragmentation of the concrete in the compressed zone are achieved. In some cases, the destruction occurs in the inclined section due to the gradual corrosion of virtually all transverse rods.
- the design codes does not allow to determine the load bearing capacity in all cases when calculating bending reinforced concrete elements with corrosion damage for a long simultaneous action of the aggressive medium and load. Difference between the theoretical and actual values is 13.7% in the direction of exceeding the theoretical values over the experimental ones. This is due to the effect of corrosion micro cracks as stress concentrators in compressed concrete, and as a result, a decrease in the strength of concrete in the presence of corrosion processes and prolonged load action;
- the difference between the experimental and calculated values of the deflections for the flow of Muexp armature is about 14.5%. For most beams, the estimated values exceeded the experimental ones. At the operating load level of 0.7 Muex, the difference between the experimental and theoretical deflections is up to 20%. At the same time, for most beams, experimental values exceeded the calculations.

The term biological corrosion denotes the processes of damage to concrete (Zhuravskaya, 2014) caused by living organisms, i.e. bacteria, mushrooms, mosses, lichens and microorganisms, settling on the surface of building structures. Bacteria, mushrooms, algae grow on concrete structures and penetrate the capillary-porous structure of the material. The products of their metabolism, such as organic acids and alkalis, destroy the components of cement stone, especially in conditions of high humidity.

The authors (Petrov, 2015) investigated the influence of defects in reinforced concrete structures, which are formed during manufacture, with the displacement of reinforcement and scraping of concrete, with torsion formation. By the action of bending moment in the flexural reinforced concrete elements can occur spatial spiral cracks and a significant reduction in the crack resistance in normal and inclined sections in 4,7 times.

The values of bending moments, when the first spiral-like cracks appear, are, on average, 4.2 times smaller than the bending moments in which the first normal cracks appear in the experimental samples of a similar design. At the same time, the presence average value ($0{,}45T_u$) reduces the crack-stability of normal cross sections of conventional single-displacement beams by 3.8 times with average values of other experimental factors.

Particularly dangerous is influence of defects and damage on bending RC elements (Voskobinik, 2011) which cause biaxial bend. In this case, there is a change of work, the nature of the stress-strain state, the strength and deformability of the element as a result of damage or defect. The set of different factors forming the biaxial bend can be divided into endogenous and exogenous (Voskobinik, 2011). As a result of the endogenous factors, the most common outcome is the change in the geometric characteristics of the cross section of the reinforced concrete beam - the displacement of the position of the center of gravity and the rotation of the main axis of inertia. As a result, the line of action of the force plane does not coincide with the main axis of inertia, which changed its position, and, therefore, there is a curvaceous bending.

The above methods are suitable only in certain conditions through their formation with emphasis on factors that significantly affect the stress-strain state of the element with certain defects and damage, but this accentuation significantly increases the accuracy of the calculation data and their relevance to the real.

Demand of a non-destructive diagnostic method is partly disclosed in the application of the method of vibration diagnosis. The main advantages of the vibration method are the ability to reflect the joint work of reinforcement with concrete, selectivity in relation to the most dangerous defects. This method expands Kad'amtsev M.I. in his work (Kadomtsev, 2012). Main emphasis is made on comparing the dynamic characteristics of the reference design with the corresponding dynamic characteristics of the model with defect and the localization of defects with the use of the method of vibration diagnostics. The following conclusions are made:

- the values of the frequencies of the own oscillations are reduced, when the size of the defect increases, and it indicates that the bending form of oscillations is the most informative characteristic for the localization of defects in the design;
- the change in the size and shape of the section, the length of the element, the elasticity of the material, the material density, the protective layer of the reinforcement, as well as the presence of such defects as the extinction of the concrete, the voids necessary for the implementation of communications, and the area of the non-density of concrete are substantially affected by the frequency of the own fluctuations of structures.
- with an increase in the area of damage, the stiffness of the beam cross sections decreases, which causes a decrease in the values of the frequencies of the own oscillations.
- the best results on the location of the defect in the construction are obtained by the method of changing the shape of the fluctuations of the reference design model and the model with the damage. The basis of this method is the criterion of modal convergence (MAC). Input parameters are the frequencies of the internal oscillations of the design and the corresponding vibration forms.
- the error of the localization of the damage to the beam was 7-9 cm when using 7 monitoring points, with the increase in the number of monitoring points along the beam, the error value decreases.

The general conclusion of this method is that the expediency of use in certain types of damage (the author considered the damage to the formation from overload), the need to further study the work of this method in other types of defects, the profitability of using this method is using a certain number of monitoring points, depending on the type of defect and the object of the study.

When disclosing the issue of vibration diagnosis of damage, attention should be paid to the comparison of existing algorithms for the detection of damage.

Based on the vibration characteristics, the methods of identification for damage are divided into four main categories: natural frequency methods, methods of form based on the mode, the method of curvature on the basis of the form, and methods that use both the form and the of the regime. In Wei's work (2016) the five investigated damage detection algorithms are analyzed, namely: method of indicator of single damage (SDI) (based on the frequency), a generalized fractal dimension method (GFD) (based on a mode of main form), method of curvature form (MSK) (based on elements curvature), a torn method smoothing (MSK) and damage index method (DIM) (based on energy from deformation) are presented in Table. 1.

Table 1. Capabilities of five comparative damage detection algorithms (Wei, 2016)

Algorithm	Single damage detection	Multiple damage detection	Large-area damage detection	Noise immunity	Sensor spacing tolerance
SDI	Yes	No	No	N/A	N/A
GFD	Yes	No	No	Excellent	Fair
MSC	Yes	Yes	Yes	Good (Good)	Good (Good)
GSM	Yes	Yes	No	Fair (Good)	Good (Good)
DIM	Yes	Yes	Yes	Fair (Excellent)	Fair (Excellent)

The modes of curvature of the shape and the method of the index of damage are relatively reliable at high measured noise and a considerable distance between the sensors. That, in turn, makes the data two algorithms satisfactory for the investigation of experimental models with damage and comparison of results based on them with other methods of studying damaged reinforced concrete elements.

The method of diagnostics is based on real-time monitoring of the operation of the element based on the impedance using PZT (lead-zirconate-titanate) for reinforced concrete structures (Park 2006). The method consist of structured monitoring based on the impedance using the connection (electromechanical properties) between the PZT overlay and the experimental structure. The electromechanical system is shown as an ideal example (Fig. 2,3). The electrical aspect of the PZT overlay is described a short-circuit impedance, and the structure of the test model is represented by a mechanical moving point impedance, which includes the effect of mass, stiffness, damping, and boundary conditions.

The PZT overlays are powered by voltage or current. The integrated electromechanical system can be electrically represented by an electrical resistance which is influenced by the dynamics of the PZT and the structure of the model. Sensitivity to SHM impedance detection is closely related to the selected frequency band. To effectively detect damage, it is necessary for the wavelength of the excitation to be smaller than the characteristic length of the damage. This method is investigated in Park's work (2006) under the action of a load with damage in the form of concrete slicers in the upper part of the beam in real time, which makes this method promising in the study of reinforced concrete with damages.

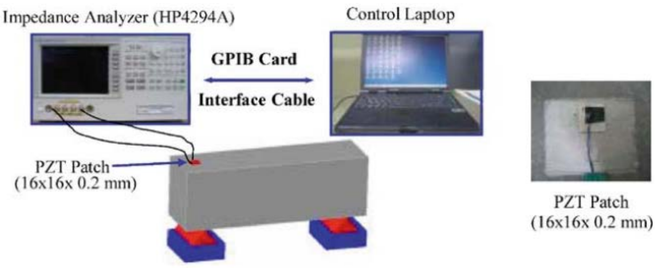

Fig. 2. Experimental setup and PZT patch attached to host structure (Park 2006)

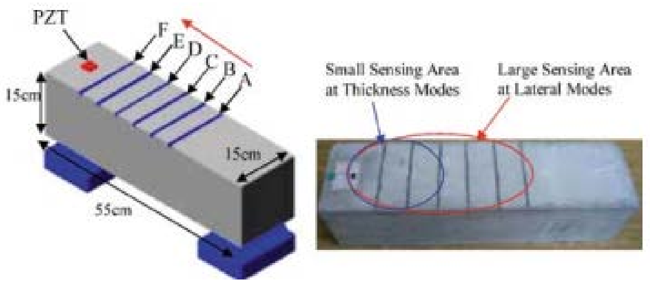

Fig. 3. Test specimen and progressive surface damage simulated by notches (Park 2006)

The method of specific electrical resistance is one of the types of non-destructive methods for investigating the corrosion of reinforcement in reinforced concrete elements. The basis of this is the dependence of the specific electrical resistance to the specific resistance of the water phase in the concrete and the fraction of volumetric water saturation of the pores, taking into account correction coefficients on the characteristics of the materials.

This method was studied in Puzanov's work (2011), with a demonstration of practical value in the detection of corrosion and its degree of development in reinforced concrete elements. Consequently, with the value of the specific electrical resistance 55 - 33 kΩ × cm corrosion was absent, and starting from the value of 11 kΩ × cm and below, the damage was detected by corrosion depending on the sharp increase in the degree of damage from the reduction of the specific electrical resistance. The general conclusions of this method are:

- the expediency of using in the diagnosis of damage to corrosion at various stages,
- -the absence of the need for damage to the element in diagnosis, the feasibility of using in the diagnosis of a large number of parts.

The possibility of using and creating computer-aided design (CAD) should also be noted. As a result of the increasing complexity of taking into account multifactor under the action of the load and other factors in the presence of damage and defects in iron-tone elements significantly increases the calculated complexity. Creation of a new CAD deserves a special attention because the impossibility of using existing for complex cases of damage and defects or a combination of them, or high labor costs. The study of the formation of a modular scheme for a highly specialized integrated CAD for the diagnosis of the technical condition of construction objects is disclosed by Yeremenko BM (Yeremenko, 2015).

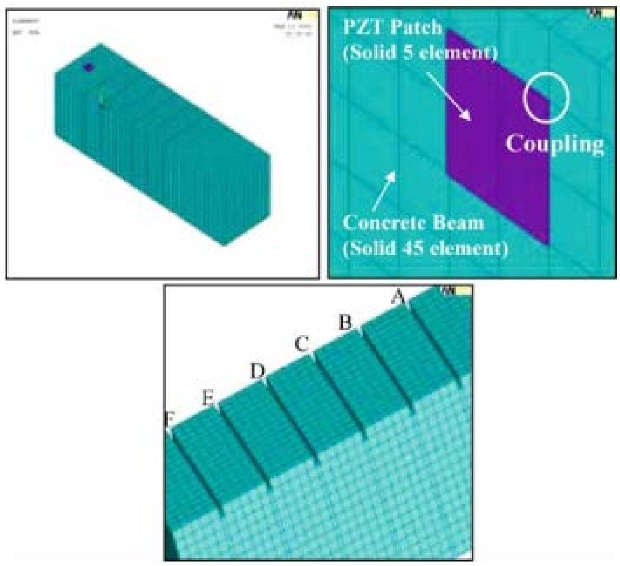

Fig. 4. FE model of PZT and concrete beam with damage (Park 2006)

3. Summary and conclusion

While analyzing research methods of bearing capacity of reinforced concrete elements in case of damage, it can be concluded that this problem requires further experimental and theoretical studies. Particularly relevant is the study of the influence of damage to the bended reinforced concrete elements obtained under the action of load, since in the current codes this possibility is not fully disclosed. It should also be noted that in such studies, modeling, using method of the finite element, damage is of significant impact on the study.

There is also a need for further development of methods for the investigation of reinforced concrete elements with typical damage, which will give a chance to accurately simulate real damage, to study the stress-strain state of such structures.

This is concern especially for the investigations of damage to the compressed concrete zone, which is a typical defect that poses a significant risk to further safety operation of structures and research of received damages and defects under the influence of load of various kinds of intensity.

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主要类型缺陷和坝龄对钢筋混凝土构件承载力的影响分析及研究方法

關鍵詞
弯曲元件
钢筋混凝土梁
损伤
缺陷
承载力

摘要
在当前的经济趋势中，需要改变建筑使用。它通常会导致建筑结构的工作负荷的价值和类型发生变化，需要对技术状态进行评级并替换或加强要素。确定受损弯曲钢筋混凝土构件残余承载力的一个重要方面是研究不同缺陷和损伤对强度和变形能力变化的影响。在文章中主要描述了损坏和缺陷的类型，描述了损坏的钢筋混凝土构件的研究方法和这些元件的使用方便性。然而，由于计算的复杂性和多因素性的考虑，大多数方法仅适用于某些缺陷和损坏。用于计算受损元件的单一方法的显着复杂性取决于元件的可能变化的应力应变状态以及某些缺陷和损坏，非完全分离的存在，其中在加载或改变受损元件期间压裂钢筋混凝土是一种复合材料，在计算其构件的联合工作时具有复杂性。