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CORROSION OF RC ELEMENTS` REINFORCEMENT AND ITS INFLUENCE ON THE STRESS-STRAIN STATE

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Abstract: The stress-strain state of reinforced concrete elements is rather complicated issue of scientific research, which integrates different factors, such as the load type, atmospheric conditions, various defects, damages, geometric deviations. It is commonly known that corrosion of reinforced concrete elements affects both the strength and deformation parameters of the structure significantly; thus, internal stresses` parameters are also influenced. Therefore, detailed theoretical investigation of this issue is the main goal of this article. The detailed literature review and thorough analysis was conducted concerning previous experimental and theoretical studies of the corrosion defects` influence on the reinforced concrete elements` stress-strain state. Existing data and results were systematized and analyzed. On the basis of provided research it could be concluded that the reinforced concrete elements` stress-strain state greatly depends on existing damages and impurities. The stress-strain state could be complicated on micro-scale due to material chemical and mechanical peculiarities; simultaneously on macro-scale the bearing capacity is of the structure could be reduced in general. In the articles existing methods for this issue simulation and evaluation are described and perspective fields for further research are identified. The practical significance of the article is due to complex approach to the research and multilateral identification of the main issue key points.

Keywords: corrosion, reinforced concrete elements, steel bars, stress-strain state

1. INTRODUCTION

Construction industry is mainly associated with significant capital investments required for new construction and dependence on external factors of scientific and technological scale, as well as on the world economic market. Therefore, the great attention is paid to the issue of optimal usage and proper exploitation of existing residential and

industrial construction funds, their optimization, reconstruction, strengthening (Tryapitsin et. al., 2019, Adhikary et. al., 2015).

Reinforced concrete structures nowadays are increasingly becoming the main choice in the construction industry (Tryapitsin et. al., 2019, Jung et. al., 2019, Bobalo et. al., 2019, Christodoulou and Goodier, 2014, Blikharskyy, 2019, Selejdak et. al., 2020, Krainskyi, 2020, Bobalo et. al., 2020). According to Jung et. al., 2019 reinforced concrete structures are commonly subjected to various negative impacts, one of the most remarkable of which are corrosion influences. During this process the strength and deformation parameters of the structure could significantly change. Therefore development of reliable methods for evaluation of reinforced concrete elements` stress-strain state due to corrosion impacts requires particular attention.

2. PURPOSE OF THE RESEARCH

The work includes detailed review of existing experimental and theoretical studies, in which corrosion defects` influence on the stress-strain state of reinforced concrete elements is investigated. Article aims to provide thorough analysis and systematization of the results of scientific works. Also, the task of the study is to outline promising areas of development of this topic and provide recommendations for further experimental and theoretical research.

3. ANALYSIS OF RECENT RESEARCH

As the reinforced concrete recently has become the most common structural material the great number of scientific works were devoted to the study of its` properties in various exploitation conditions (Indeitsev et.al., 2018, Statsenko and Mitasov, 2018, Slaitas et.al., 2020, Fouzia et. al., 2019, Blikharskyy et. al., 2020, Khmil et. al., 2019, Pavlikov et.al., 2018, Karpiuk et. al., 2019). In theoretical and experimental studies was analyzed performance of reinforced concrete elements under different loading conditions and external negative impacts.

It is important to admit, that due to specific microstructural properties of the material and its synergic nature the distribution of deformations, internal forces and non-force effects is rather complicated. Corrosion impacts with their non-uniform complex chemical and physical parameters could be the reason of significant changes in stress-strain state of the structural element. Authors (Indeitsev et.al., 2018, Statsenko and Mitasov, 2018, Slaitas et.al., 2020, Fouzia et. al., 2019, Blikharskyy et. al., 2020, Khmil et. al., 2019, Pavlikov et.al., 2018, Karpiuk et. al., 2019, Zandi, 2010, Radchenko et/al/, 2019) studied reinforced concrete elements in various complex load conditions, including permanent and short-term loading and environmental effects. Such effects were noted as plastic deformations` accumulation and calculation scheme complication, which require complex mathematical simulation models. Number of studies were also devoted to various strengthening techniques, taking into account the structures` features (Vatulia et. al., 2019, Kos and Klimenko, 2019, Azizov et. al., 2019).

Authors (Mackechnie and Alexander, 2001) [describe corrosion process as the inevitable process during which materials` components return to more stable condition under the exposure of aggressive environments. Corrosion damages have become an urgent problem in construction industry due to significant number of pathological effects on infrastructure (Karpiuk et. al., 2019, Thomas et. al., 2013, Habita, 1992). Such damages could develop rapidly and be invisible during a long period after the structural integrity had already been compromised.

With the development of external influences of the aggressive environment both quantitative and qualitative internal efforts` parameters change. Therefore, rational design and reconstruction decisions could be obtained only if the corrosion influences` on the kinetics of stress-strain changes is assessed. Obviously, the correct formulation of reconstruction decision is possible only with comprehensive assessment of a particular structural element and thorough definition of its stress-strain state (Varlamov et. al., 2019).

For today the theoretical and experimental studies of aggressive environment and local load combined effect on reinforced concrete element have not given the proper evaluation technique (Blikharskyy. et. al., 2017). As was shown (Khmil et. al., 2009), the method of these dangerous factors` assessment, proposed in normative regulations significantly overestimates the bearing capacity of corroded reinforced concrete structures. The work shows an increase in the deformability of the samples with the combined action of local load on them and sulfuric acid. The effect of corrosion on the reinforcing component of this system is associated with complex changes in the stress-strain state of the structure in general.

The decisive factor in this issue is chemical aspect of components` joint action. Authors (Indeitsev et. al., 2018) pay their attention to alkaline-aggregate reactions, which lead to accumulation of alkaline-silica gel products, subsequent internal pressures and cracking of concrete stone. In order to fully investigate this issue should be developed the set of studies, including field inspection of structures, detection and distribution of defects, aggressive conditions, monitoring of critical degradation kinetics, laboratory tests on samples collected from one or more components of the affected concrete.

The number of works (Ayinde et. al., 2019, Küter et. al., 2005) were devoted to analysis of the chloride corrosion mechanism. As additional negative factors the conditions of repeated wetting, freezing and thawing, as well as dynamic loads were specified. Reliable modeling techniques finite element analysis and ABAQUS simulation (Ayinde et. al., 2019) and probabilistic method (Küter et. al., 2005) were used. Such probabilistic approaches have recommended itself as reliable way to obtain detailed qualitative and quantitative information about the level of structural reliability. Thus, taking into consideration specifics of material degradation processes the kinetics of stress-strain changes in structural elements could be accurately predicted. However, the main obstacle to the introduction of such a technique in practical application is the large number of unsystematized probabilistic models for such processes and, accordingly, a significant amount of input data for more complex mathematical modeling.

Research (Teplý and Novák, 2012) mostly focuses on the carbonate corrosion, which is generally determined by the diffusion environmental processes and its subsequent reactivity with concrete with a corresponding decrease in pH to 8.3. After the carbonization depth reaches the steel bars, depassivation processes begin and, simultaneously the corrosion of reinforcement starts. The speed and intensity of such process is the integrated result of many parameters, including thickness and permeability of concrete, ambient temperature, relative humidity and carbon dioxide content, type and composition of concrete, gradients, hardening conditions, etc. Authors (Teplý and Novák, 2012) propose to represent in simulation techniques all the above indicated parameters as random variables of a certain range.

However, it should be noted, that the chemical processes during corrosion act simultaneously as the negative mechanical factors. Thus, as was stated (Fouzia et. al., 2019), despite the fact that some components of concrete are chemically quite passive,

availability of specific thermal and chemical environmental conditions could cause the certain gel phase formation; after that micro-cracks in the cement stone appear and the fragile destruction takes place. This aspect should be taken into consideration during the design of reinforced concrete structures, which have tendency to fragile destruction, such as prestressed reinforced concrete elements. Newly introduced simulation techniques (Dai et. al., 2020) provided reliable assessment of localized corrosion complex phenomenon and corresponding strength and prestress losses. Also non-linear character of bearing capacity reduction was noted with sharp decrease at certain level due to weak interphase interaction of the material components.

Fracture degradation was identified also by authors (Šahinagić-Isović and Cecez, 2013), where authors emphasize on the necessity to analyze the RC element as the composite structure, rather than as separate components, in particular under the negative impacts.

Le et al., 2017 in their work propose the use the combination of different approaches during corrosion process simulation. According to author (Šahinagić-Isović and Cecez, 2013) such an approach is the only possible way to reliably analyze complex degradation process and identify components of the stress-strain state of the reinforced concrete element, in particular to define the full field of deformation. Similarly (Teplý and Novák, 2012) the complex of probabilistic simulation techniques and appropriate software (software RC LifeTime, FReET-D) were used, which enabled to take into account the environmental on the design situation, boundary conditions of reinforced concrete structures

4. CONCLUSION PERSPECTIVES FOR FUTHER RESEARCH

In the article is provided the detailed review and analysis of existing experimental and theoretical studies concerning the issue of corrosion defects` influence on the stress-strain state of reinforced concrete elements. Thorough analysis and systematization of previous scientific work results is conducted and corresponding conclusions could be made. As could be seen from the review of the main scientific achievements and developments, corrosion defects in reinforcement cause significant complication of the stress-strain state and reduction of the structure bearing capacity.

In the number of works authors argue the necessity to use multi-parameter simulation techniques and probabilistic method in order to obtain reliable assessment of changes in the stress-strain state of the reinforced concrete structure. Various internal and external factors need to be taken into consideration, including sample type, nature of external load (bending, central or off-center compression), time of chemical reactions, aggressive environment, temperature, etc.

Based on conducted research in could be stated that the reinforced concrete element, subjected to corrosion impact should be investigated as the complex composite structure with corresponding synergic properties. It could be argued that it is advisable to continue experimental and theoretical research of this issue. Recommendations for further research are to conduct more complex research and formulate an appropriate method of taking into account corrosion defects. Such method will have the remarkable practical significance and could be used for more reliable decisions on reconstruction and reinforcement.

REFERENCES

Adhikary, S. D., Li, B., Fujikake, K., 2015. *Residual resistance of impact-damaged reinforced concrete beams*, Magazine of Concrete Research, 67(7), 364-378, DOI: 10.1680/macr.14.00312.

Ayinde, O. O., Zuo, X. B., Yin, G. J.,2019. *Numerical analysis of concrete degradation due to chloride-induced steel corrosion*, Advances in concrete construction, 7(4), 203-210, DOI: 10.12989/acc.2019.7.4.203.

Azizov, T. N., Kochkarev, D. V., Galinska, T. A., 2019. New design concepts for strengthening of continuous reinforced-concrete beams, In IOP Conference Series: Materials Science and Engineering, 2019, 708 (1), 012040, DOI: 10.1088/1757-899X/708/1/012040.

Blikharskyy, Y.Z., 2019. *Anisotropy of the Mechanical Properties of Thermally Hardened A500s Reinforcement*, Mater Sci, 55, 175–180, DOI: 10.1007/s11003-019-00285-0.

Blikharskyy, Z., Shnal, T., Khmil, R., 2017. *The influence of the damaged reinforcing bars on the stress-strain state of the rein-forced concrete beams*, Production Engineering Archives, 14, DOI: 10.30657/pea.2017.14.06.

Blikharskyy, Z., Vashkevych, R., Vegera, P., Blikharskyy, Y., 2020. Crack Resistance of RC Beams on the Shear, Lecture Notes in Civil Engineering, Springer, Cham, 47, 17-24, DOI: 10.1007/978-3-030-27011-7_3.

Bobalo, T., Blikharskyy, Y., Kopiika, N., Volynets, M., 2019. *Theoretical analysis of RC beams reinforced with high strength rebar's and steel plate*, IOP Conf. Series: Materials Science and Engineering, 708(1), 012045, DOI: 10.1088/1757-899X/708/1/012045.

Bobalo, T., Blikharskyy, Y., Kopiika, N., Volynets, M., 2020. *Serviceability of RC Beams Reinforced with High Strength Rebar's and Steel Plate*, Lecture Notes in Civil Engineering, Springer, Cham, 47, 25-33, DOI: 10.1007/978-3-030-27011-7_4.

Christodoulou, C., Goodier, C. I.,2014. *Corrosion management of reinforced concrete structures*, Concrete (London), 37-39.

Dai, L., Bian, H., Wang, L., Potier-Ferry, M., Zhang, J., 2020. *Prestress Loss Diagnostics in Pretensioned Concrete Structures with Corrosive Cracking*, Journal of Structural Engineering, 146(3), 04020013, 1-11, DOI: 10.1061/(ASCE)ST.1943-541X.0002554.

Fouzia, B., Fouzi, H.M., Noureddine, F., 2019. *Concrete Structures and the Aggressive Environments: Experimental and Numerical Simulation*, Conference: International Conference on Water, Informatics, Sustainability, and Environement iWISE2019, At: Carleton University – Ottawa, 1-10.

Habita, M. F., 1992. *Contribution to the Study of the Alkali-Silica-Reaction Effect, on the Mechanical Behaviour of Reinforced Concrete Beams*, PhD Thesis. Thesis for obtaining of doctorate diploma.

Indeitsev, D.A., Porubov, A.V., Skubov. D. Yu., Lukin, A.V., Popov, I. A., Vavilov, D.S. 2018. *On the influence of the microstructure on stress-strain state of the material*, Materials Physics and Mechanics, 35, 66-70, DOI: 10.18720/MPM.3512018_9.

Jung, J. S., Lee, B. Y., Lee, K. S., 2019. *Experimental study on the structural performance degradation of corrosion-damaged reinforced concrete beams*, Advances in Civil Engineering, 1, 1-14, DOI: 10.1155/2019/9562574.

Karpiuk, V. M., Syomina, Y. A., Antonova, D. V., 2019. *Bearing Capacity of Common and Damaged CFRP-Strengthened RC Beams Subject to High-Level Low-Cycle*

Loading, In Materials Science Forum, 968, 185-199, DOI:10.4028/www.scientific.net/MSF.968.185

Khmil, R., Tytarenko, R., Blikharskyy, Y., Vashkevych, R., 2019. *Influence of load level during strengthening of reinforced concrete beams on their reliability*, In IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2019, 708(1), 012054, DOI:10.1088/1757-899X/708/1/012054.

Khmil, R.E., Vashkevych, R.V., Blikharskyy, J.Z., 2009. *Stress-deformed state of reinforced concrete beams damaged by the aggressive environment*. Bulletin of the "Lviv Polytechnic" National University.Theory and practice of construction (655), 278–285.

Kos, Ž., Klimenko, Y., 2019. *The Development of Prediction Model for Failure Force of Damaged Reinforced-Concrete Slender Columns*, Tehnički vjesnik, 26(6), 1635-1641, DOI: https://doi.org/10.17559/TV-20181219093612.

Krainskyi, P., Blikharskyy, Y., Khmil, R., Vegera, P., 2020. *Crack Resistance of RC Columns Strengthened by Jacketing*, Lecture Notes in Civil Engineering, Springer, Cham, 47, 195-201, DOI: 10.1007/978-3-030-27011-7_25.

Küter, A., Geiker, M. R., Olesen, J. F., Stang, H., Dauerschmidt, C., Raupach, M., 2005. *Chloride Ingress in Concrete Cracks under Cyclic Loading*, in Proceedings of Third International Conference on Construction Materials, ConMat'05, Vancouver, Canada.

Le, D. B., Tran, S. D., Dao, V. T., Torero, J., 2017. *Deformation capturing of concrete structures at elevated temperatures*, Procedia engineering, 210, 613-621. DOI: 10.1016/j.proeng.2017.11.121.

Mackechnie, J. R., Alexander, M. G., 2001. *Repair principles for corrosion-damaged reinforced concrete structures*, Research monograph, 5.

Pavlikov, A., Kosior-Kazberuk, M., Harkav, O. 2018. *Experimental testing results of reinforced concrete beams under biaxial bending*, International Journal of Engineering & Technology, 7(3.2), 299-305, DOI: 10.14419/ijet.v7i3.2.14423.

Radchenko, A., Radchenko, P., Batuev, S., Plevkov, V., 2019. *Modeling of fracture of reinforced concrete structures under impact*, Architecture and Engineering. 4(3), 22-29, DOI: 10.23968/2500-0055-2019-4-3-22-29.

Šahinagić-Isović, M., Cecez, M., 2013. *Stress-strain state analysis of reinforced concrete beams with steel fibers*, Conference: Fiber concrete, At: Prague 1-10.

Selejdak, J., Blikharskyy, Y., Khmil, R., Blikharskyy, Z., 2020. *Calculation of Reinforced Concrete Columns Strengthened by CFRP*, Lecture Notes in Civil Engineering, Springer, Cham, 47, 400-410. DOI: 10.1007/978-3-030-27011-7_51.

Slaitas, J., Valivonis, J., Rimkus, L., 2020. *Evaluation of stress-strain state of FRP strengthened RC elements in bending. Fracture mechanics approach*, Composite Structures, 233, 111712, DOI: 10.1016/j.compstruct.2019.111712.

Statsenko, N., Mitasov, V., 2018. *Control of stress-strain state in double-span reinforced concrete beams*, In MATEC Web of Conferences, EDP Sciences, 143(3), 01007, DOI: 10.1051/matecconf/201814301007.

Teplý, B., Novák, D., 2012. Limit states of concrete structures subjected to environmental actions, Engineering Mechanics, 99, 1363–1367.

Thomas, M.D.A., Fournier, B., Folliard, K.J., 2013. *Alkali-Aggregate Reactivity (AAR) Facts Book* (No.FHWA-HIF-13-019), Federal Highway Administration. Office of Pavement Technology, United States.

Tryapitsin, Y., Pakhomov, V., Voinov, S., 2019. *Analysis and regulation of the stress-strain state of structures with reliability*, E3S Web of Conferences. EDP Sciences, 138, 01016, DOI: 10.1051/e3sconf/201913801016.

Varlamov, A., Rimshin, V., Tverskoi, S., 2019. *A method for assessing the stress-strain state of reinforced concrete structures*, EDP Sciences. In E3S Web of Conferences, 91, 02046, DOI: 10.1051/e3sconf/20199102046.

Vatulia, G., Lobiak, A., Chernogil, V., Novikova, M., 2019. *Simulation of Performance of CFST Elements Containing Differentiated Profile Tubes Filled with Reinforced Concrete*, In Materials Science Forum, 968, 281-287, DOI: 10.4028/www.scientific.net/MSF.968.281.

Zandi, H. K., 2010. *Structural behaviour of deteriorated concrete structures*, Chalmers University of Technology.