ISSN 2522-4182

DOI:10.32347/2522-4182.16.2025.87-99
UDC:624.012.45:624.072.2:539.3

CHANGING IN THE STRESS-STRAIN STATE WITH NON-UNIFORM DAMAGED REINFORCED CONCRETE

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Abstract. This article considers the influence of local one-sided damage on the stress-strain state of a reinforced concrete beam.The research is aimed at analyzing changes in load-bearing capacity, deformations, and potential failure mechanisms caused by unilateral damage.Reinforced concrete is one of the most widespread and important construction materials used in various engineering structures, from residential and public buildings to bridges and other infrastructure facilities.However, despite its high durability and significant reliability, reinforced concrete may undergo substantial damage under the influence of various aggressive environmental factors [1].

All these factors lead to increased deformations, a decrease in load-bearing capacity, and may result in the failure of the reinforced concrete structure.Particular attention should be paid to defects caused by unilateral moisture exposure [2], when moisture penetrates from only one side of the structure, leading to an unpredictable stress-strain behavior during design and operation.As a result, concrete spalling may occur [3].

Unilateral moisture exposure can have various effects on different types of structures depending on their dimensions, loads, and operating conditions. To study such damage, a special experimental method was developed to simulate localized damage on the side surface of reinforced concrete beams.

Within the framework of the study, an analysis was carried out between theoretical modeling using the finite element method in the LIRA software and the experimental results. The Digital Image Correlation (DIC) method was applied, which allows for the detection of cracks and deformations[4].

The DIC method provides high accuracy in tracking the distribution of deformations on the surface of a specimen in real time, which makes it extremely useful for studying the development of damage and its impact on the load-bearing capacity of reinforced concrete structures [5].

The obtained research results make it possible not only to improve the understanding of the behavior of reinforced concrete elements under conditions of one-sided wetting but also to significantly increase the efficiency of structural health monitoring.

This will allow potential problems to be detected more promptly [6] and ensure the necessary preventive measures to avoid severe damage, thereby improving the safety and durability of structures during operation.

Keywords: damage; deformation; defects; digital image correlation; reinforced concrete beams.

INTRODUCTION

In modern construction, reinforced concrete plays a key role as one of the most reliable and widespread structural materials.

Its extensive use is due to the combination of high strength, stiffness, and durability.

However, over time, reinforced concrete is exposed to adverse environmental influences that may lead to its gradual degradation [7].

The main threats to reinforced concrete structures include concrete carbonation, reinforcement corrosion, moisture exposure, aggressive chemicals, and temperature fluctuations [8].These factors cause changes in the internal structure of the material, the formation of cracks, and a reduction in the bond between concrete and reinforcement, which significantly affects the load-bearing capacity and safety of structures [9].Special attention should be given to elements damaged as a result of moisture exposure on the lateral surface [10].

Such conditions can cause local stresses, crack development, delamination of the concrete surface layer, and reinforcement corrosion [11].

Early diagnostics and detailed investigation of such damage are crucial for ensuring structural reliability.Modern non-destructive testing methods [12], particularly Digital Image Correlation (DIC), allow for high-precision assessment of the deformation state of structures and identification of potential failure zones at early stages [13].Studying these processes will contribute to the development of effective monitoring methods and ensure detailed analysis of the condition of reinforced concrete structures.To study the damage mechanisms caused by unilateral wetting, an experimental investigation was conducted simulating localized damage on the lateral surface of a beam, which allows for analysis of changes in its stress-strain state.

Under real operating conditions, reinforced concrete structures are often subjected to a combination of adverse factors.

The cumulative effect of these factors leads to the gradual deterioration of concrete, the formation of cracks, and the destruction of the protective layer.As a result, the stress-strain state of the structure changes [14,15], significantly deviating from the conditions anticipated during the design phase.In particular, local stress concentrations, redistribution of internal forces, displacement of the neutral axis, and deformation asymmetry may occur, which can lead to skew bending [16], deflections in unexpected directions, and a reduction in load-bearing capacity [17].

Thus, operational damage causes nonlinear and spatial changes in the stress-strain state [18], which are difficult to consider using standard design procedures.

This necessitates the implementation of experimental control methods, periodic diagnostics, and updated calculation models that take into account the actual operating conditions of the structure [19,20].

MAIN STUDY

To validate the theoretical assumptions and compare them with the results of experimental investigations, numerical modeling of a reinforced concrete beam with localized damage was performed using the finite element method (FEM) [21,22,23].

This approach made it possible to assess the stress distribution, deformation pattern, and the influence of the damage on the overall stiffness of the structure prior to conducting the physical experiment.The obtained computational data were compared with the results of full-scale tests to verify the accuracy of the model and validate the theoretical assumptions. The study used a specimen of a reinforced concrete beam with a rectangular cross-section and geometric dimensions of 2100×100×200 mm.

The beam was simply supported on two supports with a clear span of 1900 mm.

To create a bending load, two concentrated forces were applied symmetrically at one-third of the span from each support.

Load control was performed using dynamometers, and the load was applied incrementally in steps of 10% of the expected load-bearingcapacity.This setup allows for the creation of a constant pure bending region in the central part of the beam and ensures a more uniform distribution of internal forces.To simulate localized damage caused by one-sided wetting, a defect measuring 200×200×30 mm was made on the side surface of the beam in the pure bending zone (Fig.1).

The damage was introduced prior to the beginning of the loading process.

Fig. 1. General view of the damage
Рис.1. Загальний вигляд пошкодження

This damage simulates conditions in which reinforced concrete is exposed to prolonged moisture from one side, a scenario typical of many real operating environments, such as water infiltration or cycles of freezing and thawing. Such exposure leads to delamination of the concrete layer, increased deformations and cracking, and, as a consequence, to a reduction in load-bearing capacity, a change in the inclination of the neutral axis, and an alteration of the stress-strain state that deviates from the design assumptions.For the experimental procedure, three-dimensional digital image correlation (3D-DIC) was used on the damaged side of the reinforced concrete beam.This system allows for precise tracking of displacements and deformations on the specimen surface during loading (Fig. 2).

Fig. 2. View from the damaged side
Рис.2. Вигляд із сторони пошкодження.

To implement digital image correlation, a system consisting of four cameras was used: two of them were oriented to capture the entire length of the beam, while the other two focused on the pure bending zone for detailed analysis of deformations in this critical area.

On the opposite side of the reinforced concrete beam, deformations were measured using micro-indicators (Fig. 3), which provided wireless data transmission to a personal computer in real time.

Fig. 3. Placement of the micro-indicators.
Рис.3. Схема розташування мікроіндикаторів

The instrument layout provided for the installation of the first micro-indicator at a height of 20 mm from the top edge of the beam, while the remaining sensors were mounted at 30 mm intervals along the height of the cross-

ISSN 2522-4182

section.To monitor horizontal displacements deflection micro-indicatior were installed on the side surface of the beam in three zones: ts of the study showed that the presence of localized damage leads to a reduction in the load-bearing capacity of the beam compared to the reference undamaged beam, as confirmed by both numerical and experimental data presented in the article [24].Notably, significant horizontal displacements of the beam were recorded during the experiment.This behavior inddirectly under the points of load application and in the central part of the span.

Similarly, micro-indicators were placed to record vertical displacements.

Thanks to the combination of digital image correlation, non-contact measurements using micro-indicators, and numerical modeling by the finite element method, a comprehensive picture of the behavior of the reinforced concrete beam with localized damage was obtained.In particular, deformations of the compressed concrete zone, reinforcement, as well as vertical and horizontal deflections of the structure were analyzed.The resulicates a disturbance in the stiffness balance across the width of the cross-section, which potentially leads to a change in the geometric position of the neutral axis.Such damage causes the neutral axis to shift, resulting in the beam effectively working under conditions of skew bending.

This can be critical from the standpoint of further structural serviceability, as it causes displacements and stresses not anticipated in the design.Such a change in deformation behavior is an important indicator of the transition of the structure to a more complex stress state, in which stresses and deformations develop not only in the principal bending plane.Figure 4 presents a comparative graph illustrating the relationship between the bending moment M and the reinforcement strain εyk, obtained using three methods: from micro-indicators, from digital image correlation, and from the LIRA software.

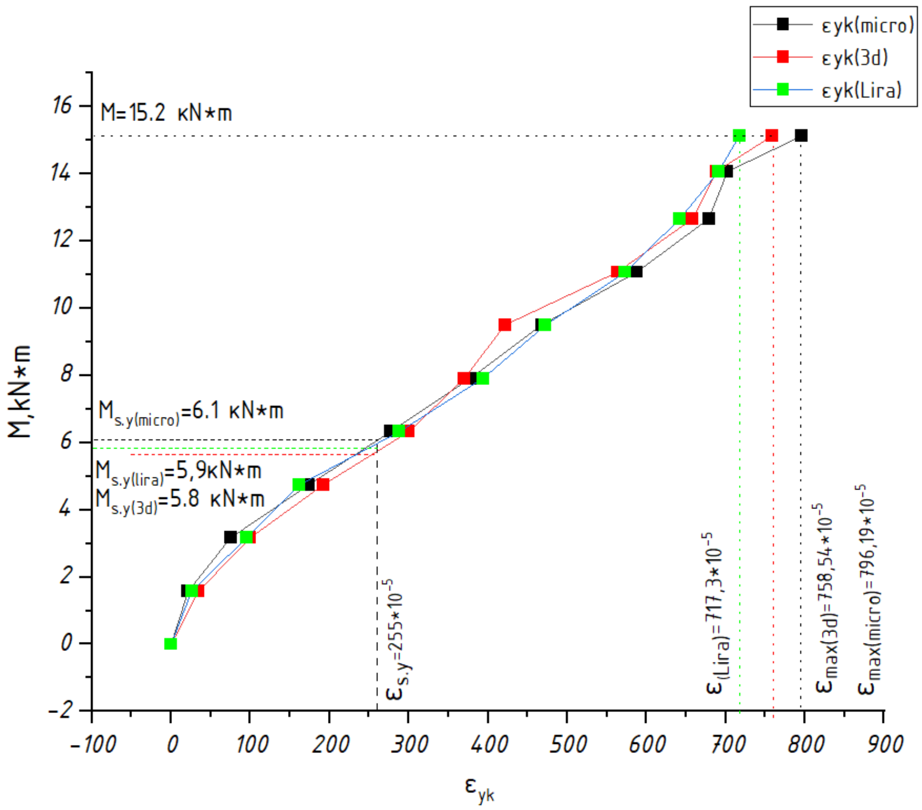

Fig. 4. Comparative graph of reinforcement strains
Рис.4. Порівняльний графік деформацій арматури

ISSN 2522-4182

The analysis of the graphs makes it possible to determine the moment at which the yield strength of the reinforcement is reached for each method, as well as the maximum reinforcement strain values for each approach.

The graph shows the yield moment values as follows: $M_{s,y(micro)}$=6.1kNm; $M_{s,y(LIRA)}$=5.9kN·m, $M_{s,y(3D)}$=5.8kN·m. The results obtained using micro-indicators, image correlation, and theoretically using the LIRA software demonstrate close agreement and are also presented in Table 1.

Table.1. Reinforcement strains: experimental and numerical data
Табл.1. Деформації арматури: експериментальні та числові дані

M,кН*m	ε_{yk}(micro)	ε_{yk}(3d)	ε_{yk}(Lira)	3d та micro	Lira vs micro
1,5825	21,63	34,5	25,85	59.5%	19.5%
3,165	75,19	99,78	95,25	32.7%	26.7%
4,7475	174,07	192,4	162,23	10.5%	6.8%
6,33	277,07	300,1	288,25	8.3%	4.0%
7,9125	378,01	370,28	393,9	2.0%	4.2%
9,495	467,6	421,2	472,65	9.9%	1.1%
11,0775	588,13	563,74	573,6	4.1%	2.5%
12,66	678,77	658,35	642,3	3.0%	5.4%
14,06	702,4	688,3	691,2	2.0%	1.6%
15,12	796,19	758,57	717,3	4.7%	9.9%

Figure 5 shows the strain graph of the compressed concrete zone near the undamaged edge.

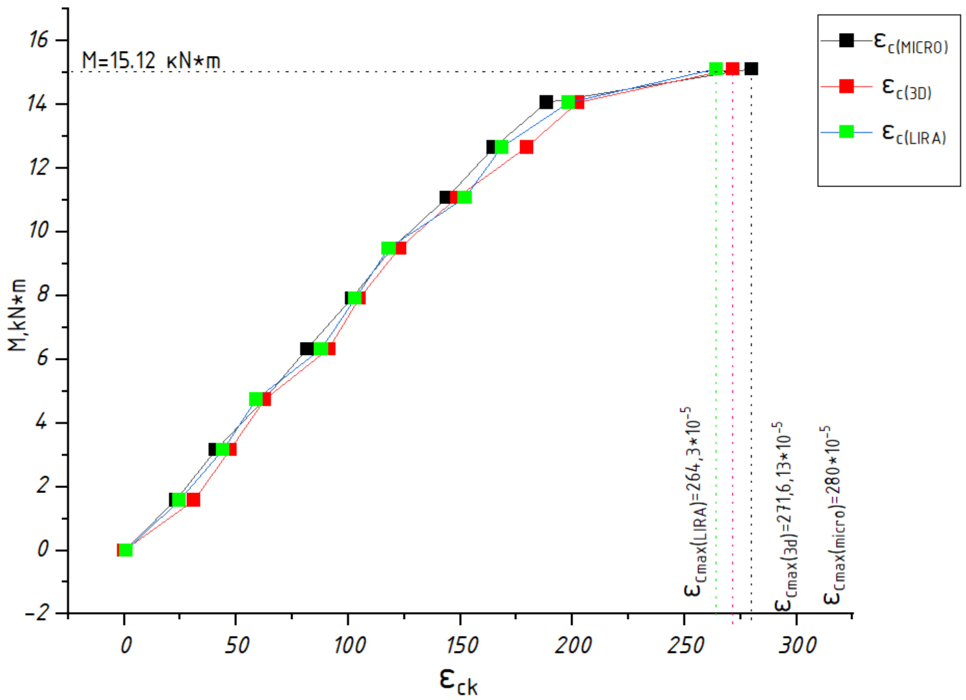

Fig. 5. Comparative graph of concrete compression zone strains
Рис.5. Порівняльний графік деформацій стиснутої зони бетону

ISSN 2522-4182

The obtained graphs demonstrate a high level of consistency between the results of different methods, indicating the reliability of the measurements and the effectiveness of each approach for assessing the deformational behavior of concrete.

The maximum strains recorded by all methods fall within a narrow range (264–280 × 10^{-5}), which further confirms the accuracy of both the experiment and the numerical modeling.

The maximum compressive strains of the concrete, obtained by all methods, exceeded the normative limit established for concrete of class C35/45 according to DBN [25].

Table 2 presents the comparative values of compressive strains in the concrete, which confirm the overall increase in strain with the growth of the bending moment.

Minor discrepancies between the experimental and numerical data remain within acceptable limits and support the validity of the applied approaches.

Table.2. Concrete compression zone strains: experimental and numerical data
Табл.2. Деформації стиснутої зони бетону:експериментальні та числові дані.

M,кН*m	$\varepsilon_{ck(micro)}$	$\varepsilon_{ck(3d)}$	$\varepsilon_{ck(Lira)}$	3d vs micro	Lira vs micro
1,5825	23	31,2	24,6	35%	7.0%
3,165	41	47,3	44,17	15%	7.7%
4,7475	62,5	62,8	58,83	0.5%	5.9%
6,33	81,5	91,2	87,88	11%	7.8%
7,9125	101,5	104,8	103,1	3.3%	1.6%
9,495	119,5	122,8	118,1	2.8%	1.2%
11,0775	144	148,4	152,1	3.1%	5.6%
12,66	165	179,5	168,4	8.8%	2.1%
14,06	188,5	202,4	198,33	7.4%	5.2%
15,12	280	271,6	264,3	3.0%	5.6%

Figure 6 shows the graph of vertical deflections of the reinforced concrete beam.

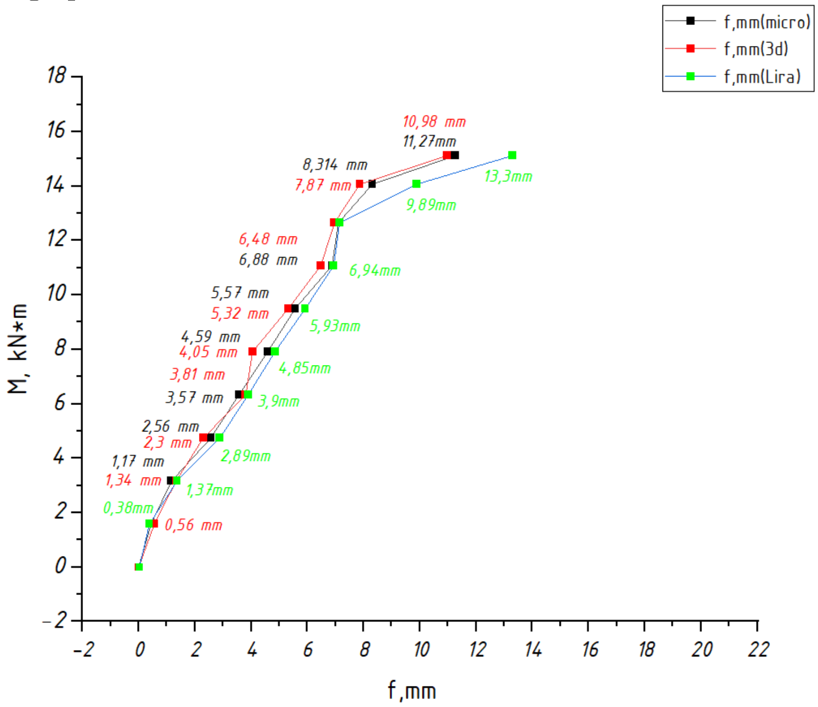

Fig. 6. Comparative graph of vertical deflections
Рис.6. Порівняльний графік вертикальних прогинів

Throughout the entire load range, the results show overall agreement between the experimental data and the numerical method.

Before reaching physical failure, the theoretical deflection values exhibit slightly greater deviation from the experimental results.

This is due to the fact that the modeling assumes somewhat idealized conditions for the behavior of the reinforced concrete beam (Table 3).**Table.3.** Vertical deflections: experimental and numerical data

Табл.3. Вертикальні прогини: експериментальні та числові дані

М,кН*м	f,mm (micro)	f,mm (3d)	f,mm (Lira)	3d vs micro	Lira vs micro
1,5825	0,448	0,56	0,387	25%	13,6%
3,165	1,176	1,34	1,37	13,95%	16,5%
4,7475	2,568	2,3	2,89	10,44%	12,4%
6,33	3,571	3,81	3,9	6,69%	9,21%
7,9125	4,592	4,05	4,85	11,8%	5,62%
9,495	5,57	5,32	5,93	4,49%	6,46%
11,0775	6,88	6,48	6,94	5,81%	0,87%
12,66	7,11	6,97	7,15	1,97%	0,56%
14,0666	8,314	7,87	9,89	5,34%	18,6%
15,121	11,27	10,98	13,3	2,57%	18,1%

Figure 7 presents the results of horizontal displacements.

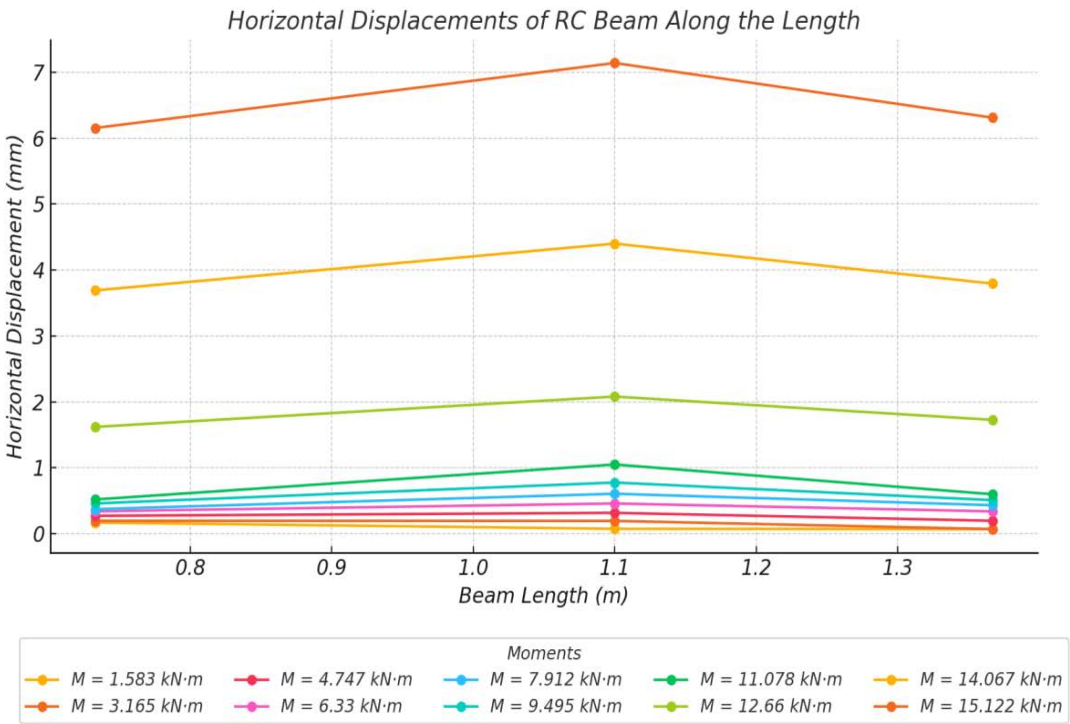

Fig. 7. Horizontal deflections of the specimen along the beam length
Рис.7. Горизонтальні прогини зразка по довжині балки

The results show that horizontal displacements gradually increase with increasing load, with the largest values observed in the damaged zone (Table.4).

The lateral displacement of the beam indicates a shift of the neutral axis and the beam's behavior under skew bending conditions.

Thus, tracking horizontal displacements is a critical step in studying the performance of damaged reinforced concrete elements.

Their analysis allows for a more accurate assessment of the impact of a local defect on the overall deformation behavior of the beam, as well as for incorporating this influence into numerical models.

Table 4. Horizontal displacements of the beam .
Табл.4. Горизонтальні переміщення балки

M,кN*m	Horizontal displacement,mm
1,5825	0,074
3,165	0,194
4,7475	0,316
6,33	0,458
7,9125	0,606
9,495	0,74
11,0775	1,05
12,66	2,08
14,06667	4,4
15,12167	7,139

The experiment recorded the presence of a residual deflection of the reinforced concrete beam after unloading (Fig. 8).

This residual deflection indicates ireversible changes in the structure of both the concrete and the reinforcement. Such residual deflections are important for assessing the remaining load-bearing capacity of the structure after loading.

A visual inspection of the specimen after testing also confirmed the presence of residual vertical deflection in the loading zone, which correlates with the measurement results

Fig. 8. Residual horizontal deflection
Рис.8. Залишковий горизональний прогин

Fig. 9. View of the reinforced concrete beam after the experiment from the damaged side.
Рис.9. Вигляд залізобетонної балки після експерименту із сторони пошкодження

CONCLUSIONS

In this study, localized damage was successfully modeled on the side surface of a reinforced concrete beam to simulate the effect of one-sided moisture exposure. The experiment, conducted using the three-dimensional Digital Image Correlation (DIC) method, enabled both qualitative and quantitative assessment of strain distribution and tracking of damage development in the area of the local defect. The results confirm that unilateral moisture exposure can significantly influence the stress-strain state of the structure.

A promising direction for future research is the study of the influence of local damage on the behavior of reinforced concrete elements under loading. The continued use of the three-dimensional DIC method will make it possible to observe the initiation and propagation of cracks in real time due to operational damage.

This approach will contribute to a deeper understanding of structural behavior and support the development of more effective diagnostic methods and predictions of the residual service life of reinforced concrete structures. The obtained results established a correlation between the damage and the deformation behavior A shift of the neutral axis, skew bending formation, development of horizontal displacements, and the appearance of asymmetric deformations were observed. A comparative analysis was carried out for the strains obtained using micro-indicators, DIC, and LIRA software.

The average deviation of reinforcement strain between DIC and micro-indicators was 13.7%, and between LIRA and micro-indicators – 8.3%.The average deviation of compressive concrete strain between DIC and micro-indicators was 9.3%, and between LIRA and micro-indicators – 5.3%. All values fall within the allowable experimental error.

Vertical deflections in the damaged zone reached 11.27 mm (according to micro-indicators), which correlates well with the calculated values of 10.98 mm (3D DIC) and 13.3 mm (LIRA model).The maximum reinforcement strains were 280×10^{-6}, while horizontal deflection exceeded 7 mm. The obtained numerical results confirm the shift of the neutral axis and the beam's behavior under skew bending conditions.

REFERENCES

1. **Mykhalevskyi N. A., Vegera P. I., & Blikharskyi Z. Y., (2023)**. The influence of damage to reinforced concrete beams on strength and deformability: the review. *Theory and Building Practice, 5(1), 112-119. https://doi.org/10.23939/jtbp2023.01.112*
2. **Fu, C., Ye, H., Jin, N., & Huang**, Y. (2020). Chloride penetration in reinforced concrete beams under combined sustained loading and drying–wetting cycles. *Journal of Materials in Civil Engineering*, *32*(4), 04020025. *https://doi.org/10.1061/(ASCE)MT.1943-5533.0003076*
3. **Liu, Fang & Tonghuan, Zhang & LUO, Tao & Zhou, Mengzhen & Zhang, Kunkun & Ma, Weiwei. (2020).** Study on the Deterioration of Concrete under Dry-Wet Cycle and Sulfate Attack. Materials (Basel, Switzerland). https://www.mdpi.com/1996-1944/13/18/4095
4. **Destrebecq, J. F., Toussaint, E., & Ferrier, E. J. E. M. (2011).** *Analysis of cracks and deformations in a full scale reinforced concrete beam using a digital image correlation technique. Experimental Mechanics, 51, 879-890.* https://doi.org/10.1007/s11340-010-9358-y
5. **Ruocci, G., Rospars, C., Moreau, G., Bisch, P., Erlicher, S., Delaplace, A., & Henault, J. M. (2016).** Digital Image Correlation and Noise-filtering Approach for the Cracking Assessment of Massive Reinforced Concrete Structures. *Strain, 52(6), 503 - 521 https://doi.org/10.1111/str.12192*
6. **Lacidogna, G., Piana, G., Accornero, F., & Carpinteri, A. (2020)**. Multi-technique damage monitoring of concrete beams: acoustic emission, digital image correlation, dynamic identification. *Construction and Building Materials, 242, 118114. https://doi.org/10.1016/j.conbuildmat.2020.118114*
7. **Blikharskyy, Y., Vashkevych, R., Kopiika, N., Bobalo, T., & Blikharskyy, Z. (2021).** Calculation residual strength of reinforced concrete beams with damages, which occurred during loading. *In IOP Conference Series: Materials Science and Engineering (Vol. 1021, No. 1, p. 012012). IOP Publishing.*

https://iopscience.iop.org/article/10.1088/1757-899X/1021/1/012012/meta

8. **Hu, J. Y., Zhang, S. S., Chen, E., & Li, W. G. (2022)**. A review on corrosion detection and protection of existing reinforced concrete (RC) structures. *Construction and Building Materials*, *325*, 126718. https://doi.org/10.1016/j.conbuildmat.2022.126718
9. **Semko, Oleksandr & Filonenko, Olena & Yurin, Oleg & Avramenko, Yurii & Mahas, Nataliia. (2023)**. Characteristic damages of reinforced concrete structures of the covering exposed to moisture. *AIP Conference Proceedings*. 030039. https://doi.org/10.1063/5.0120020.
10. **Bonić, Z., Ćurčić, G. T., Davidović, N., & Savić, J. (2015).** Damage of concrete and reinforcement of reinforced-concrete foundations caused by environmental effects. *Procedia engineering, 117, 411–418.* https://doi.org/10.1016/j.proeng.2015.08.187
11. **Vidal, T., Castel, A., & François, R. (2004).** Analyzing crack width to predict corrosion in reinforced concrete.*Cement and concrete research,34(1),165174* https://doi.org/10.1016/S0008-8846(03)00246-1
12. **Dongyang, Li & Huang, P.Y. & Chen, Zhan-Biao & Yao, Guowen & Guo, Xin & Zheng, Xiaohong & Yang, Yi. (2020).** Experimental study on fracture and fatigue crack propagation processes in concrete based on DIC technology. *Engineering Fracture Mechanics. 235. 107166.* https://doi.org/10.1016/j.engfracmech.2020.107166
13. **Perera, R., Huerta, C., Torres, L., Baena, M., Barris, C. (2023).** Concrete Beam Screening Through DIC Images. *In: Ilki, A., Çavunt, D., Çavunt, Y.S. (eds) Building for the Future: Durable, Sustainable, Resilient. fib Symposium 2023. Lecture Notes in Civil Engineering, vol 350. Springer, Cham.* https://doi.org/10.1007/978-3-031-32511-3_28
14. **Pavlikov A. M., & Diachenko Ye. V. (2004)** Determination of the angle of the neutral line in calculations of the strength of the rectangular section of reinforced concrete elements under bi-axial bending in the case of a triangular form of a compressed zone. *Scientific and technical collection. Urban utilities, 55, 324-328. (in Ukrainian).* http://eprints.kname.edu.ua/2627/
15. **Lin,S.C.,Li,D.,&Yang,B.(2019).** Experimental study and numerical simulation on damage assessment of reinforced concrete beams. *International journal of impact engineering*, *132*, 103323. https://doi.org/10.1016/j.ijimpeng.2019.103323
16. **Voskobiinyk, O.P, Kitaiev O.O., Makarenko Ya.V., Buhaienko Ye.S. (2011)**. Experimental investigation of reinforced concrete beams with defects and damages that cause the skew bending. *Academic journal. Industrial Machine Building, Civil Engineering, 1(29), 87-92. (in Ukrainian).* http://reposit.pntu.edu.ua/handle/PoltNTU/8074
17. **Malipatil, Kiran & Itti, S.. (2021).** Stress Intensity Factor and Damage Index of Reinforced Concrete Beam. http://10.1007/978-981-15-4779-9_19.
18. **Fayyad, Tahreer & Lees, J.(2014)**: Application of Digital Image Correlation to Reinforced Concrete Fracture. *Procedia Materials Science. 3* https://doi.org/10.1016/j.mspro.2014.06.256
19. **Sanz-Diez de Ulzurrun Casals, Gonzalo & Zanuy, Carlos. (2023)**. Assessment of the Bending Behaviour of RC Beams Under Impact Loads with DIC. https://doi.org/10.1007/978-3-031-32519-9_22.
20. **Anastasopoulos, D., De Roeck, G., & Reynders, E. P. (2019).** Influence of damage versus temperature on modal strains and neutral axis positions of beam-like structures. *Mechanical Systems and Signal Processing*, *134*,*106311.* https://doi.org/10.1016/j.ymssp.2019.106311
21. **Mykhalevskyi, N.A., Vegera, P.I., & Blikharskyy, Z.Y. (2023)**. Analysis of the effect of uneven damage of reinforced concrete beam using the FEMAP software package. *Modern construction and architecture, 6, 54-61.* http://visnyk-odaba.org.ua/2023-06/6-6.pdf
22. **Klymenko Ye.V., Antoniuk N.R., & Polianskyi K.V. (2019).** Modeling the work of damaged reinforcedconcrete beams in the SC “LIRA-SAPR”. *Bulletin of the Odessa State Academy of Construction and Architecture,77, 58-65.(In Ukrainian)* http://dx.doi.org/10.31650/2415-377X-2019-77-58-65.

23. **Santoro, M. G., & Kunnath, S. K. (2013).** Damage-based RC beam element for nonlinear structuralanalysis. *Engineering structures*, *49*, 733-742. https://doi.org/10.1016/j.engstruct.2012.12.02
24. **Mykhalevskyi N. A., Vegera P. I., & Blikharskyi Z. Y., (2025)**. Investigation of stress-strain parametrs in RC beams using DIC. *Theory and Building Practice, 7(1), 31-41*.https://doi.org/10.23939/jtbp2025.01.031
25. **Constructions of buildings and structures (2011)**. Concrete and reinforced concrete structures. Basic principles. DBN V.2.6-98:2009. *State Building Codes of Ukraine. . Kyiv: Ministry of Regional Development and Construction of Ukraine (in Ukrainian).* URL:http://interiorfor.com/wp-content/uploads/2017/01/26_98_2009.pdf

LITERATURE

1. **Mykhalevskyi N. A., Vegera P. I., & Blikharskyi Z. Y., (2023)**. The influence of damage to reinforced concrete beams on strength and deformability: the review. *Theory and Building Practice, 5(1), 112-119. https://doi.org/10.23939/jtbp2023.01.112*
2. **Fu, C., Ye, H., Jin, N., & Huang**, Y. (2020). Chloride penetration in reinforced concrete beams under combined sustained loading and drying–wetting cycles. *Journal of Materials in Civil Engineering*, *32*(4), 04020025. *https://doi.org/10.1061/(ASCE)MT.1943-5533.0003076*
3. **Liu, Fang & Tonghuan, Zhang & LUO, Tao & Zhou, Mengzhen & Zhang, Kunkun & Ma, Weiwei. (2020).** Study on the Deterioration of Concrete under Dry-Wet Cycle and Sulfate Attack. Materials (Basel, Switzerland). https://www.mdpi.com/1996-1944/13/18/4095
4. **Destrebecq, J. F., Toussaint, E., & Ferrier, E. J. E. M. (2011).** *Analysis of cracks and deformations in a full scale reinforced concrete beam using a digital image correlation technique. Experimental Mechanics, 51, 879-890.* https://doi.org/10.1007/s11340-010-9358-y
5. **Ruocci, G., Rospars, C., Moreau, G., Bisch, P., Erlicher, S., Delaplace, A., & Henault, J. M. (2016).** Digital Image Correlation and Noise-filtering Approach for the Cracking Assessment of Massive Reinforced Concrete Structures. *Strain, 52(6), 503 -521* *https://doi.org/10.1111/str.12192*
6. **Lacidogna, G., Piana, G., Accornero, F., & Carpinteri, A. (2020)**. Multi-technique damage monitoring of concrete beams: acoustic emission, digital image correlation, dynamic identification. *Construction and Building Materials, 242, 118114. https://doi.org/10.1016/j.conbuildmat.2020.118114*
7. **Blikharskyy, Y., Vashkevych, R., Kopiika, N., Bobalo, T., & Blikharskyy, Z. (2021).** Calculation residual strength of reinforced concrete beams with damages, which occurred during loading. *In IOP Conference Series: Materials Science and Engineering (Vol. 1021, No. 1, p. 012012). IOP Publishing.* https://iopscience.iop.org/article/10.1088/1757-899X/1021/1/012012/meta
8. **Hu, J. Y., Zhang, S. S., Chen, E., & Li, W. G. (2022)**. A review on corrosion detection and protection of existing reinforced concrete (RC) structures. *Construction and Building Materials, 325,126718. https://doi.org/10.1016/j.conbuildmat.2022.126718*
9. **Semko, Oleksandr & Filonenko, Olena & Yurin, Oleg & Avramenko, Yurii & Mahas, Nataliia. (2023)**. Characteristic damages of reinforced concrete structures of the covering exposed to moisture. *AIP Conference Proceedings. 030039. https://doi.org/10.1063/5.0120020*.
10. **Bonić, Z., Ćurčić, G. T., Davidović, N., & Savić, J. (2015).** Damage of concrete and reinforcement of reinforced-concrete foundations caused by environmental effects. *Procedia engineering, 117, 411–418.* https://doi.org/10.1016/j.proeng.2015.08.187
11. **Vidal, T., Castel, A., & François, R. (2004).** Analyzing crack width to predict corrosion in reinforced concrete.*Cement and concrete research,34(1),165174 https://doi.org/10.1016/S0008-8846(03)00246-1*
12. **Dongyang, Li & Huang, P.Y. & Chen, Zhan-Biao & Yao, Guowen & Guo, Xin & Zheng, Xiaohong & Yang, Yi. (2020).** Experimental study on fracture and fatigue crack propagation processes in concrete based on DIC technology. *Engineering Fracture Mechanics. 235. 107166.* https://doi.org/10.1016/j.engfracmech.2020.107166
13. **Perera, R., Huerta, C., Torres, L., Baena, M., Barris, C. (2023).** Concrete Beam Screening Through DIC Images. *In: Ilki, A.,*

Çavunt, D., Çavunt, Y.S. (eds) Building for the Future: Durable, Sustainable, Resilient. fib Symposium 2023. Lecture Notes in Civil Engineering, vol 350. Springer, Cham. https://doi.org/10.1007/978-3-031-32511-3_28

14. **Павліков,А.М.,Дяченко,Є.В. (2004)** Визначення кута нахилу нейтральної лінії при розрахунках міцності прямокутного перерізу залізобетонних елементів при двохвісному згині у випадку трикутної форми стисненої зони. Науково-технічний збірник «Міське господарство», 55, 324–328. *http://eprints.kname.edu.ua/2627/*
15. **Lin,S.C.,Li,D.,&Yang,B.(2019).** Experimental study and numerical simulation on damage assessment of reinforced concrete beams. *International journal of impact engineering*, *132*, 103323. https://doi.org/10.1016/j.ijimpeng.2019.103323
16. **Воскобійник,О.П.,Кітаєв,О.О., Макаренко,Я.В., & Бугаєнко,Є.С. (2011).** Експериментальні дослідження залізо-бетонних балок з дефектами та пошкодженнями, які викликають косий згин**.** *Академічний журнал. Промислове машинобудування, цивільне будівництво, 1(29),87-92 .http://reposit.pntu.edu.ua/handle/PoltNTU/8074*
17. **Malipatil, Kiran & Itti, S.. (2021).** Stress Intensity Factor and Damage Index of Reinforced Concrete Beam. *http://10.1007/978-981-15-4779-9_19*.
18. **Fayyad, Tahreer & Lees, J.(2014)**: Application of Digital Image Correlation to Reinforced Concrete Fracture. *Procedia Materials Science. 3* https://doi.org/10.1016/j.mspro.2014.06.256
19. **Sanz-Diez de Ulzurrun Casals, Gonzalo & Zanuy, Carlos. (2023)**. Assessment of the Bending Behaviour of RC Beams Under Impact Loads with DIC. *https://doi.org/10.1007/978-3-031-32519-9_22*.
20. **Mykhalevskyi, N.A., Vegera, P.I., & Blikharskyy, Z.Y. (2023)**. Analysis of the effect of uneven damage of reinforced concrete beam using the FEMAP software package. *Modern construction and architecture, 6, 54-61. http://visnyk-odaba.org.ua/2023-06/6-6.pdf*
21. **Anastasopoulos, D., De Roeck, G., & Reynders, E. P. (2019).** Influence of damage versus temperature on modal strains and neutral axis positions of beam-like structures. *Mechanical Systems and Signal Processing, 134,106311.* https://doi.org/10.1016/j.ymssp.2019.106311
22. **Клименко, Є. В., Антонюк, Н. Р., & Полянський, К. В. (2019).** Моделювання роботи пошкоджених залізобетонних балок в пк «Ліра-Сапр». *Вісник Одеської державної академії будівництва та архітектури,77,58-65.* http://dx.doi.org/10.31650/2415-377X-2019-77-58-65.
23. **Santoro, M. G., & Kunnath, S. K. (2013).** Damage-based RC beam element for nonlinear structuralanalysis. *Engineering structures*, *49*, 733-742. https://doi.org/10.1016/j.engstruct.2012.12.02
24. **Mykhalevskyi N. A., Vegera P. I., & Blikharskyi Z. Y., (2025)**. Investigation of stress-strain parametrs in RC beams using DIC. *Theory and Building Practice, 7(1), 31-41.* https://doi.org/10.23939/jtbp2025.01.031
25. **Міністерство регіонального розвитку та будівництва України. (2011).** Будівлі та споруди. Бетонні та залізобетонні конструкції. Основні положення (ДБН В.2.6-98:2009) *http://interiorfor.com/wp-content/uploads/2017/01/26_98_2009.pdf*

ЗМІНА НАПРУЖЕНО – ДЕФОРМОВАНОГО СТАНУ ПРИ ОДНОБІЧНОМУ ПОШКОДЖЕННІ ЗАЛІЗОБЕТОННИХ БАЛОК

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Анотація. У цій статті розглядається вплив локального однобічного пошкодження на напружено-деформований стан залізобетонної балки. Дослідження спрямоване на аналіз змін несучої здатності, деформацій та потенційних механізмів руйнування внаслідок одностороннього пошкодження**.** Залізобетон є одним із найпоширеніших і найважливіших будівельних матеріалів, що використовується в різноманітних інженерних конструкціях, від житлових і громадських будівель до мостів і інших інфраструктурних об'єктів. Однак,

незважаючи на свою високу довговічність і велику надійність, залізобетон може піддаватися значним пошкодженням під впливом різних агресивних факторів зовнішнього середовища.

Усі ці фактори спричиняють збільшення деформацій, зниження несучої здатності, що може призвести до руйнування залізобетонної конструкції. Особливу увагу слід приділяти дефектам, що виникають внаслідок однобічного зволоженням, коли волога проникає лише з одного боку конструкції, що призводить до непередбачуваного проектуванням НДС. Внаслідок цього виникає лущення бетону.

Однобічне намокання може мати різноманітний вплив на різні типи конструкцій, залежно від їх розмірів, навантажень та умов експлуатації. З метою дослідження таких пошкоджень було розроблено спеціальну експериментальну методику моделювання локального пошкодження на бічній поверхні залізобетонних балок. Для цього в межах дослідження було проведено аналіз між теоретичним моделюванням, що виконане за допомогою методу скінченних елементів в ПК «ЛІРА» та експериментом. У ході дослідження застосовано метод цифрової кореляції зображень (Digital Image Correlation — DIC), що дозволяє фіксувати тріщини та деформації. Метод DIC забезпечує високу точність у відстеженні розподілу деформацій на поверхні зразка в реальному часі, що робить його надзвичайно корисним для вивчення розвитку пошкоджень та їх вплив на несучу здатність у залізобетонних конструкціях.

Отримані результати дослідження дають змогу не лише покращити розуміння роботи залізобетонних елементів в умовах однобічного намокання, а й значно підвищити ефективність моніторингу технічного стану будівельних конструкцій.

Це дозволить більш оперативно виявляти потенційні проблеми і забезпечити необхідні заходи для попередження значних пошкоджень, що в свою чергу збільшить безпечність та довговічність конструкцій у процесі експлуатації.

Ключові слова: пошкодження деформація; дефекти; цифрова кореляція зображень; залізобетонні балки.

Стаття надійшла до редакції -22.05.25 р.