RESEARCH ON CONCRETE PROPERTIES BY DIC METHOD

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Abstract. Reliable measurement of strains in the material is essential in studying the building structure stress-strain state. The practice of operating concrete and reinforced concrete elements used in the construction industry shows that achieving the ultimate equilibrium state in these elements takes place in localized places. After the long-term operation of reinforced concrete structures, the concentration of stresses and strains is localized within such places, which can lead to the development of irreversible processes. Determining the stress-strain state based on classical criteria does not always give an exact answer. In such cases, the load-bearing capacity of structural elements must be assessed based on standards and invariant mechanical characteristics of materials, by which real strength and durability can be established. When the body is deformed, both on the surface and in the middle of the material, the process is accompanied by various breaks and changes in the phase field of the speckle image in the zones of singularities and various surface inhomogeneities. It is practically impossible to quantitatively assess the stressed zones of the material surface using speckle interferometry methods since the phase component is not considered in the case of a correlation fragment in speckle patterns. At the same time, the digital image correlation (DIC) methods can be used to estimate displacement and strain fields without restrictions. Therefore, such approaches can be effective technologies for determining the stress-strain state on smooth surfaces and parts with a stress concentrator. This article presents the results of testing concrete using DIC. A method of testing concrete samples using the process of determining strains by the method of digital image correlation and monitoring strains using sub-micron indicators has been developed. Transverse strains of concrete up to and including the moment of destruction of concrete samples were determined.

Keywords: strain, DIC, concrete, experiment.

Introduction

Reinforced concrete structures are the most common in industrial and civil construction [1-5]. However, various environmental influences [6-8] damage reinforced concrete structures [9-15]. To date, many works are devoted to research on restoring and strengthening such structures [16-18]. To choose a more optimal method of restoration and strengthening, more detailed methods of testing materials, in particular, concrete, are needed [19]. Also, concrete research is essential for reinforced concrete structures and concrete structures such as foundations [20-21].

One of the modern methods of testing is the technique of using digital image correlation (digital image correlation) [22]. The method of digital image correlation (DIC) is usually used in the study of the stress-strain state of building structures, in particular, it is widely used in the mechanics of the destruction of steel structures [23]. Research is underway to use digital image correlation in the study of concrete and reinforced concrete structures [24; 25].

The method of digital image correlation (DIC) is usually used in studies of the stress state of building structures as one of the non-interferometric methods [26]. It has been widely discussed in scientific works [23-26] as a method of combining a theoretical approach with parameters of controlled accuracy and experimental data for in-depth analysis of the structure. Thus, a reliable model of the behavior of the structural element can be obtained for further numerical calculations or practical use.

In general, the DIC method can be characterized as an optical measurement with digital image processing and numerical calculations [27; 28]. Its wide availability can be explained both by the large number of special software, both VIC (Correlated Solutions Company), and ARAMIS (GOM Company) and others, as well as by its ease of use. This technique requires a digital camera with a high-quality digital matrix and a special pattern of randomly placed black dots on the examined surface (speckles).

As stated in the work [27], the method is based on the comparison of relative displacements of surface points made at a specific stage and allows determining both the relative components of strains and obtaining the full field of displacements and strains in the measurement zone.

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Determination of concrete strains using this method of digital image correlation is relevant as this will make it possible to determine strains on the full plane of the sample, and thanks to high-speed cameras – at the moment of rapid destruction of the samples.

Materials and methods

To achieve the goal and objectives of the research, a concrete prism of size 150x150x600 mm of class C50/60 was formed. The surface of the prism was cleaned and leveled to a smooth surface using a grinder and a grinding stone. After that, the surface of the prism was cleaned with a solvent to remove dust residues. After that, spectra were applied to determine the strains using the DIC method. The spectra were applied using a laser printer (Fig. 1).

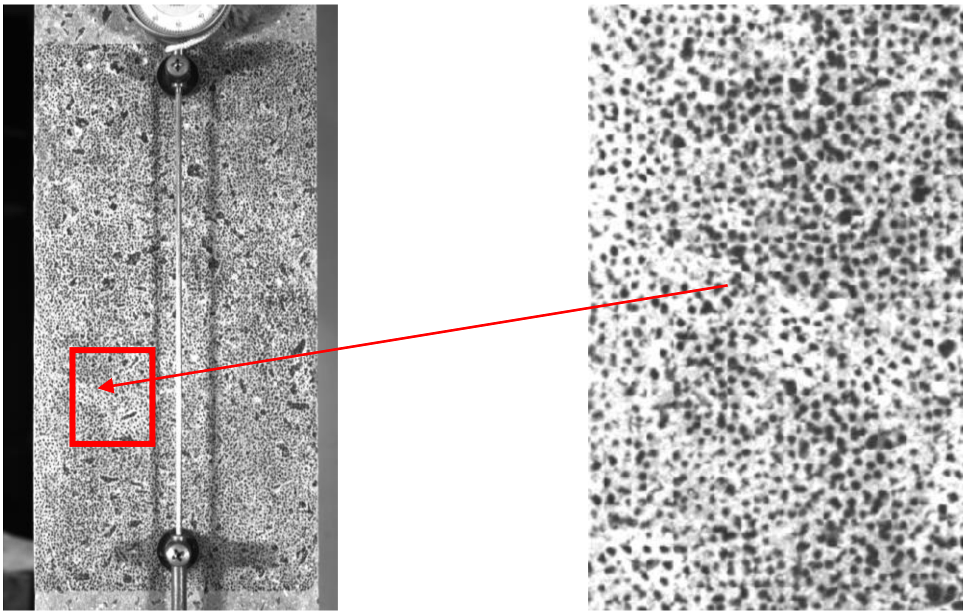

Fig. 1. **Applied speckles on a concrete prism**

To determine the strains using the digital image correlation method, 2 cameras "Grasshopper 3" of the Flir company with a Computar F25/2.8 lens and a Sigma 70-200 mm f2.8 APO EX DG HSM Macro II lens were used (Fig. 2). Strains for image correlation were recorded at a speed of 250 ms. 2 LED lamps are used for lighting. Since the press does not have the possibility to record the load in time, a camera with a speed of 50 frames per sec was additionally used to record the load.

a) b)

Fig. 2. **Experimental setup:** a – research prism, two high-speed cameras and lighting; b – laptop for image registration

The load was applied uniformly at the same speed to the physical destruction of the test samples.

Results and discussion

The resulting images were processed using VIC-2D software to obtain vertical and transverse strains. The advantage of the image correlation method is the possibility to obtain strains and, accordingly, stresses of the entire surface of the test sample.

Thus, if to analyze the horizontal (transverse) stresses for a concrete prism of class C50/60, it is possible to see the appearance of internal cracks in the sample before their appearance on the outside, that is, at the moment when it is not yet possible to visually fix the cracks (Fig. 3).

a) b) c)

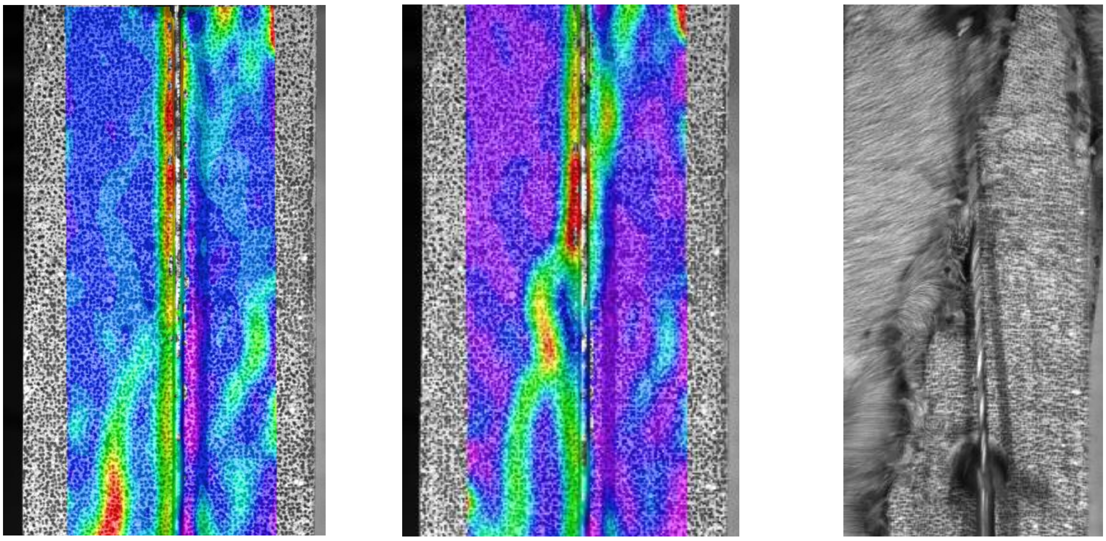

Fig. 3. **Nature of the distribution of transverse strains and appearance of internal cracks:** a – at the load 37.0 MPa; b – at the load 37.5 MPa; c – at the destruction moment

As a result, the strains at the corresponding stresses for the concrete prism in the longitudinal and transverse directions were obtained. To determine the strains, using the method of digital image correlation, virtual extensometers were installed in the software complex within the middle of the sample and on a base of 200 mm.

The main task of this article is to test the use of the digital image correlation method to determine the Poisson's ratio. To check the reliability of the results, a mechanical micro-indicator was installed vertically on the prism (Fig. 4).

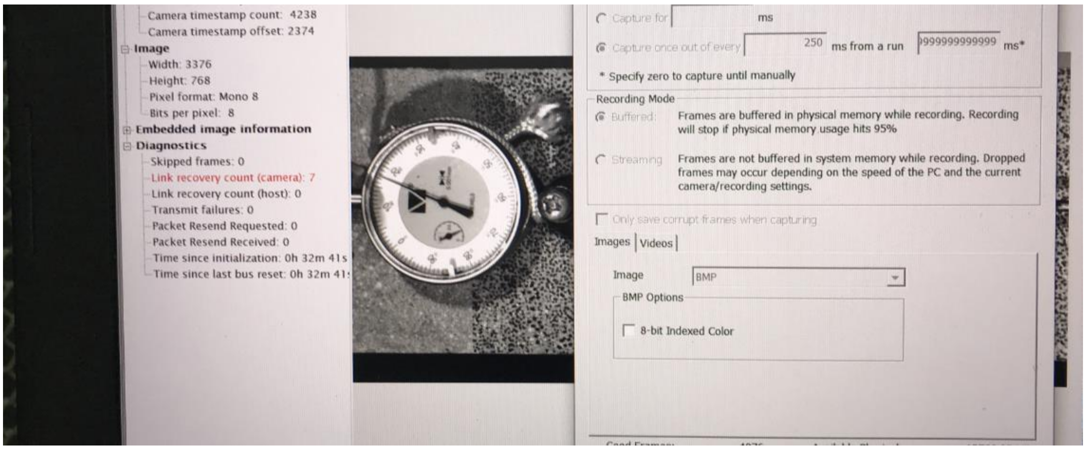

Fig. 4. **General view of image recording for the digital image correlation method with a mechanical indicator installed**

The results of the determination of vertical deformations by the method of digital correlation of the image and the mechanical indicator are shown in Table 1. According to the normative documents of DSTU B V.2.7-217:2009, the Poisson's ratio is determined at the level of 30% of the destructive load. At this level, the Poisson's ratio was 0.3. Additionally, the table shows the values at higher load levels, including concrete failure. The reliability of the results was checked using sub-micron indicators with an accuracy of 0.001 mm on a base of 200 mm. As a result of the determination of vertical deformations by the method of digital correlation of the image relative to the mechanical indicators, the deviation was 4%...10%, respectively. This indicates the possibility of using the digital image correlation method to determine relative deformations.

Table 1

Results of experimental determination of transverse and horizontal strains – definition of Poisson's ratio

Stress, MPa	Vertical Strains, $\times 10^{-5}$			Horizontal Strains, $\times 10^{-5}$	Poisson's ratio	Approx. Poisson's ratio
	Mechanical Gauges on 200 mm base	Digital Image Correlation	Deviation, %			
17.095	67.5	72.69	8.43	18.45	0.255	0.27
28.551	99.5	95.4	3.89	42.2	0.416	0.44
34.010	129	120.81	6.18	61.0	0.487	0.50
39.403	177.8	158.4	9.92	138.82	0.774	0.74

The Poisson's ratio is defined as the ratio of transverse to longitudinal strains, according to the standard. The experimental results of determining the Poisson's ratio at all load stages are graphically presented in Fig. 5. On the graph in Fig. 5, the blue line shows the result of determining the Poisson's ratio using the digital image correlation method, and the red line shows the approximate values.

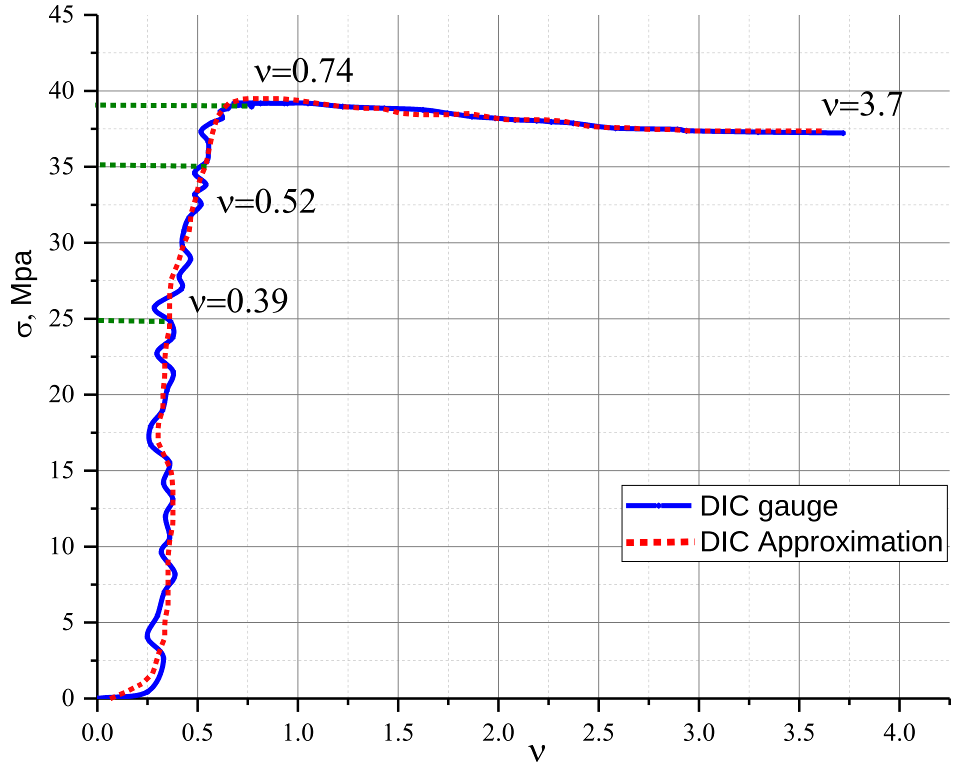

Fig. 5. **Graph of the Poisson's ratio change depending on the load**

As a result of research, it was established that the Poisson's ratio for C50/60 class concrete in the stress range of 0…25 MPa is 0.0...0.39, in the range of 25...35 MPa - 0.39...0.52, and in the range of 35...39 MPa – 0.51...0.74. After destruction on the descending branch, the Poison's ratio increased from 0.74 to 3.7.

Conclusions

1. When determining the vertical deformations of concrete by the method of digital correlation, the deviation of the image in comparison with the mechanical indicator is within 4...10%, which can be considered a satisfactory convergence.
2. According to the developed method of using digital image correlation to determine relative vertical and horizontal deformations, it is possible to determine the Poisson's ratio up to and including the moment of destruction of concrete samples. The Poisson's ratio for the example sample at a load level of 30% of the destructive one was 0.3, and in general, in the elastic stage, it reaches the value of 0.74. It should be noted that in the plastic stage the value of the coefficient increases from 0.74 to 3.7.
3. During the research, the advantages of using the digital image correlation method to determine the relative deformations of the entire examined plane of the sample, both in the longitudinal and transverse directions, were established, which makes it possible to study the change in relative deformations and the movement of individual points or areas during the study of concrete surfaces up to concrete destruction.

Author contributions

Conceptualization, Y.B., investigation, Y.B., J.S. and R.K., methodology, Y.B., J.S. and R.K., formal analysis, Y.B., Z.B. and J.S., writing – review and editing, Z.B., R.K. and J.S., supervision, Y.B., validation, R.K. and J.S., writing – original draft preparation, Y.B., R.K., Z.B. and J.S., visualization, Y.B. All authors have read and agreed to the published version of the manuscript.

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