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Influence of the percentage of reinforcement damage on the bearing-capacity of RC beams

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Abstract: This article presents the test results of reinforced concrete beams with different percentages of reinforcement damage. One of the main causes of structural damage is corrosion. The main cause of corrosion is an aggressive environment, which can endanger the environmental ecology. During the study, the effect of damage to reinforced concrete beams was investigated. The beams were produced full-sized, 100x200x2100 mm. According to the research program, 6 beams were tested, including undamaged control samples with a single reinforcement bar of Ø20 mm – BC-1 and BC-2; samples with a reinforcement bar of Ø20 mm with about 10% damage – BD-3 and BD-4; samples with a reinforcement bar of Ø20 mm with about 20% damage – BD-5 and BD-6. The reinforcement bar was damaged before concreting the samples. As a result, it was determined that a reduction in the bearing-capacity of the reinforced concrete beams depended on the percentage of damage to the reinforcement bar.

Keywords: reinforced concrete, full-size sample, bearing capacity, damaged reinforcement

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Introduction

Damage to reinforced concrete structures and the determination of residual resource is a topical issue (Fouzia et al., 2019, Mongelos, 2018).

At present, there a small number of field studies into building elements that are operated under the influence of aggressive environments (Dai et al., 2020; Christodoulou & Goodier, 2014; Ayinde et al., 2019). Data was collected on the durability of reinforced concrete beams used in industrial structures, the exponential dependence of the depth of neutralization of concrete (corrosion fracture) on time, as well as the ratio for estimating the depth of the corrosion of reinforcing bars (Geiker & Justnes, 2012). The obtained dependences make it possible to calculate the period of reliable operation of structural elements. Also, the magnetic method of determining the depth of corrosion in concrete structures was analyzed (Elyasigorji et al., 2019).

The analysis of the performed research shows that the corrosion properties and corrosion resistance of concrete or reinforcement, as well as the chemical processes occurring during corrosion in these materials are studied in depth, but a small number of experimental studies of the impact of aggressive environments on reinforced concrete structures as integral structures have been conducted.

Isolated studies on the combined effect of corrosion and load do not give a complete picture of the work of reinforced concrete structures in an aggressive environment, including the destruction of structures. It is noted that studies into the durability of reinforced concrete structures operated in various aggressive environments are mainly solved not by determining the parameters of the stress-strain state, but by the parameters of the rate of corrosion processes, chemical transformations and determining their impact on the geometric parameters of the structures' durability of designs.

1. Objective

The aim of the work is to carry out experimental studies on reinforced concrete beams with different percentages of reinforcement damage. Then, using the results of the experimental tests, determine the reduction of load-bearing capacity in the reinforced concrete beams depending on the percentage of damage.

2. Materials and methodology

According to the research program, 6 beams were tested. Among them were undamaged control samples with a single reinforcement of Ø20 mm – BC-1 and BC-2; samples with a Ø20 mm reinforcement bar with about 10% damage – BD-3 and BD-4; samples with a Ø20 mm reinforcement with about 20% damage – BD-5 and BD-6. The reinforcement was damaged before concreting the samples.

The reinforcement of samples consisted of A500C steel bars with a diameter of 20 mm. Reinforcement of the compressed zone and transverse reinforcement were made of Ø5 B 500 bars. The transverse reinforcement Ø5 B500C had a 75 mm spacing (Fig. 1).

Experimental samples used in the research had the length of 2100 mm, 100 mm width, and 200 mm height. The beams' concrete composition: C:S:R = 1:1, 16:2, 5 with W/C = 0.375. The cement used – M-500, sand quartz without impurities with a size module M_k = 2.00, granite rubble of fractions 5-10 mm – 66%, 10-20 mm – 33%. Specific characteristics of the reinforcement material degradation are presented on the basis of samples with predetermined material properties. The samples are thermally Ø20 mm A500C steel bars. Attention should be paid to the specific non-uniform properties of the modeled samples, described in the previous study (Blikharskyy et al., 2020).

The test specimens were tested for bending under short-term load. The load level was monitored by means of annular dynamometers, which simultaneously served as a hinged support on one side and a fixed support on the other side of the beam with a run of 1900 mm. The load was applied in the form of two concentrated forces at the third of the span of the beam by means of a hydraulic jack and a distribution traverse (Fig. 2).

Fig. 1. The general view of reinforcement (*own research*)

Fig. 2. The test machine and RC beam during testing (*own research*)

Deformations of the reinforcement and the compression of the concrete were measured using clock-type micro indicators with divisions of 0.001 mm. Five deflection gauges were installed on the beam to measure the deflections.

The load was applied in 5% stages until the first cracks appeared with a holding time of 15 minutes. After each condition, which mainly corresponded to a bending moment of 30%, the load was continued in steps of 10% for 15 minutes. Exposure was performed to stabilize the plastic deformations of the concrete. For the first 10 minutes, the appearance of new cracks and the development of previous cracks were monitored. The widths of the cracks were measured using a BCH-2 microscope. The divisions of the microscope was 0.05 mm. On the “side-free” side of the beams, the cracks were numbered in turn and then sketched, indicating the corresponding stages of loading. For the next 5 minutes, the readings of the micro indicators and deflection gauges were recorded.

3. Results

The results of the study are shown in Table 1.

Table 1. Results of the experimental research

Sample mark	The percentage of reinforcement damage %	Moment which corresponds to the limit strain of the reinforcement kNm	Average	Deviation in the bearing capacity values %	Moment which corresponds to the limit strain of the concrete kNm	Average	Deviation in physical destruction %
BC-1	0	21.7	20.8	–	24.6	23.7	–
BC-2		19.9			22.8		
BD-3	10	17.9	18.4	11.5	20.8	20.1	15.2
BD-4		18.9			19.4		
BD-5	20	14.5	15.1	27.4	17.2	16.8	29.1
BD-6		15.7			16.4		

Beams BC-1 and BC-2 were controls without damage. In the beam BC-1, according to the experimental results, the moment which corresponds to the limit strain of the reinforcement bar was $M_{s,y}^{exp} = 21.7$ kNm, further loading was accompanied by the significant increase in the strain of the reinforcement and concrete. The load at which the compressed concrete reached its limit strain was at $M_{ult}^{exp} = 23.7$ kNm. For BC-2 the moment which corresponds to the limit strain of the reinforcement was $M_{s,y}^{exp} = 19.9$ kNm. The load at which the compressed concrete reached its limit strain was $M_{ult}^{exp} = 22.8$ kNm.

The reinforcement bars of beams BD-3 and BD-4 were damaged by 10%. In beam BD-3, according to the experimental results, the moment which corresponds to the limit strain of the reinforcement was $M_{s,y}^{exp} = 17.9$ kNm. The load at which the compressed concrete reached its limit strain was $M_{ult}^{exp} = 20.8$ kNm. In beam BD-4, according to the experimental tests, the load at which the deformation of the main rebar reached its yield strength was $M_{s,y}^{exp} = 18.9$ kNm. The load at which the compressed concrete reached its limit strain was $M_{ult}^{exp} = 19.4$ kNm.

The reinforcement bars of beams BD-5 and BD-6 were damaged by 20%. In beam BD-3, according to the experimental results, the moment which corresponds to the limit strain of the reinforcement bar was $M_{s,y}^{exp} = 14.5$ kNm. The load at which the compressed concrete reached its limit strain was $M_{ult}^{exp} = 17.2$ kNm. In beam BD-4, according to the experimental tests, the load at which the deformation of the main rebar reached its yield strength was $M_{s,y}^{exp} = 15.7$ kNm. The load at which the compressed concrete reached its limit strain was $M_{ult}^{exp} = 16.4$ kNm.

Conclusions

One of the main causes of structural damage is corrosion. The main cause of corrosion is an aggressive environment, which endangers the environmental ecology. During the study, the effect of damage to reinforced concrete beams was investigated. 6 reinforced concrete beams were tested. For the reinforced concrete beams with 10% of the reinforcement bar damaged, the bearing-capacity corresponding to the limit strain of the reinforcement bar decreased by 11.5% and the bearing-capacity corresponding to the limit strain of the concrete, decreased by 15.2%. For reinforced concrete beams with 20% of the reinforcement bar damaged these values decreased by 27.4 and 29.1%, respectively.

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