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Basic parameters of crack resistance of conventional and damaged reinforced concrete beams strengthened by carbon plastic under the action of a high-level load.

Parámetros básicos de resistencia al agrietamiento de vigas de hormigón armado convencionales y dañadas reforzadas con plástico de carbono bajo la acción de una carga de alto nivel.

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ABSTRACT

The main results of experimental studies of the fracture resistance of conventional and damaged and brought to the limit state according to I group in the previous experiments of reinforced concrete beams reinforced with fiberglass carbon fiber (CFRP) in the lower stretched zone and at the supporting areas. According to the adopted methodology, a full-scale experiment was performed on a four-factor three-level Box-Bank B4 plan. The tests of the prototypes were carried out according to the scheme of a single-track free-beam, alternately loaded from above, then from below by two concentrated forces without changing its (beam) position. During testing of the test specimens-beams for the action of short- term one-time and small-cycle loads, the formation, development and width of crack opening on their surface were monitored. The width of the opening of normal cracks was determined at the level of the stretched working armature, and the inclined ones - in the middle of the height of the beam in places where it was visually greatest. Due to the adopted methodology, new experimental data were obtained to substantially refine the physical models of the inclined sections of the precast concrete structures by the action of low-cycle reloading of high levels, resulting in the first identified systemic effect on fracture toughness.

Keywords: concrete, reinforcement, carbon fiber fabric (CFRP), reinforced concrete beam, normal and inclined cracks, deformations.

RESUMEN

Los principales resultados de los estudios experimentales de la resistencia a la fractura de convencional y dañado y llevado al estado límite de acuerdo con el grupo I en los experimentos anteriores de vigas de hormigón armado reforzadas con fibra de vidrio de fibra de carbono (CFRP) en la zona estirada inferior y en las áreas de apoyo. . De acuerdo con la metodología adoptada, se realizó un experimento a gran escala en un plan Box-Bank B4 de cuatro factores y tres niveles. Las pruebas de los prototipos se llevaron a cabo de acuerdo con el esquema de una viga libre de una sola pista, cargada alternativamente desde arriba, luego desde abajo por dos fuerzas concentradas sin cambiar su posición (viga). Durante la prueba de las probetas-vigas de prueba para la acción de cargas únicas a corto plazo y de ciclo pequeño, se monitoreó la formación, el desarrollo y el ancho de la abertura de la grieta en su superficie. El ancho de la abertura de las grietas normales se determinó al nivel de la armadura de trabajo estirada y las inclinadas, en el medio de la altura de la viga en los lugares donde era visualmente más grande. Debido a la metodología adoptada, se obtuvieron nuevos datos experimentales para refinar sustancialmente los modelos físicos de las secciones inclinadas de las estructuras de hormigón prefabricado mediante la acción de recargas de bajo ciclo de altos niveles, dando como resultado el primer efecto sistémico identificado sobre la tenacidad de la fractura.

Palabras clave: hormigón, armadura, tejido de fibra de carbono (CFRP), viga de hormigón armado, fisuras normales e inclinadas, deformaciones.

INTRODUCTION

During operation or during spans reinforced concrete structures undergo significant damage and a significant reduction in bearing capacity, especially for low-cycle reloading actions. In this regard, it becomes necessary to restore their performance and/or increase in bearing capacity. However, in the current design standards there are no recommendations for determining the residual bearing capacity of such structures and calculating their reinforcement. Known methods of restoring operability and strengthening the structure by increasing the section by attaching additional metal or reinforced concrete elements to them. But the methods for calculating this gain are also imperfect. It is proposed to restore the operability of these structures by strengthening their stretched parts of the (CFRP), and experimental studies will form the basis for the improvement of the deformation method for calculating their bearing capacity by the authors.

Strengthening building structures is also carried out using composite materials reinforced with carbon, ar copper, polyester and glass fibers. Their indisputable advantages are high strength, resistance to aggressive influences, ease of repetition of any form of construction, minimal labor intensity of the device at the construction site (Klaus Friedrich & Ulf Breuer,2015).

MATERIALS AND METHODS

The resistance of reinforced concrete elements of the joint action of transverse forces and bending moments due to the action of low-cycle sign-post loads of high levels is one of the most important and not fully studied problem both in the theory of reinforced concrete and in real design (Posobie,et.al,2005). Indefinite repetition during operation and change in the sign of the load can lead to consequences qualitatively different from obtained when calculating for a constant load of maximum intensity, for which, in fact, most of the current norms are oriented design.

As shown by a review of literary sources, in researchers have not developed a single idea about influence of the specified load on the bearing capacity of the research elements yet. Most of them indicates its decrease at low-cycle load. However, some of them (E.M. Babich, et.al,1976) claims to be slightly re-cycling load operating levels ($\eta \leq 0.70$) can lead to increased strength spanning reinforced concrete elements, up to 20%, which requires additional explanations and experimental confirmation.

Resistance of reinforced concrete spans reinforced with CFRP damaged during operation or during combat operations, for actions low-cycle reloading at high levels has not yet been studied at all. At tension of CFRP have a linear relationship between stresses and strains to failure. The properties of the CFRP are mainly determined by the type, orientation and number of reinforcing fibers (Selejdak, J,et.al.2019). Mechanical properties of all CFRP systems, regardless of their type, are determined by the test results of samples layered material with an estimate of the volumetric fiber content, which must be at least 60%, according to the recommendations of GOST 25.601-80. Therefore, research in the specified directions is important and relevant.

According to the accepted methodology, a full- scale experiment is performed by a three-level chotiroh factor Box-Benk plan B4. Factors were varied according to the literature taking into account the sources which showed that the most influential factor X_1 is the value of the relative span of the cut a/h_0, which varied at three levels: $a = h_0$, $2h_0$ and $3h_0$. Second to the magnitude of the impact, as a rule, such a constructive factor as the class of heavy concrete: $X_2 \rightarrow$ C16/20, C30/35, C40/55, and the third - the value (amount) of transverse reinforcement on in the support areas: $X_3 \rightarrow \rho_w$ = 0,0016; 0.0029; 0.0044. The fourth factor is the external influence factor X_4 and the level of alternating load: $\eta = \pm 0.50; \pm 0.65; \pm 0.80$ on the actual bearing capacity, that is, the magnitude of the lateral load at which the opening width of inclined cracks wk exceeded 0.4 mm, and the deflection boom was $f \geq 1/150$.

Experimental beam samples were stored in normal heat and humidity conditions at a temperature of 20 ± 2 ° C and almost 100% air humidity for 100 ... 110 days. Testing of prototypes was carried out according to the scheme of a single-span forked beam, alternately loaded from above and then from below by two concentrated forces without changing its (beam) position .

Before the main experiment, at first, 25 research beams (twin specimens) of the first series were tested in turn for action single short-time step increasing load almost to destruction when the opening width of the sloped cracks and boom deflections exceeded permissible values wk> 0.8 mm, f ≥ l / 150). After for this, similar research beams of the second and third series were tested under the influence of alternating and sign-postal low-cycle transverse loads of the indicated levels in accordance with the test base N = 20 cycles, after which the sample was pumped, almost to destruction or achievement limit state, if this did not happen earlier in previous cycles. Criteria destruction of prototypes served to achieve the limiting values of deformations in concrete or reinforcement, excessively large opening (up to 1mm) oblique (more often) or normal (less often) cracks, significant increase (up to 15mm) boom deflection, no increase or decline (by 15% or more) in the pressure gauge display of the power plant pumping station. After bringing the prototype beams of series 3 to the limiting state with groups I and II, the damaged lower stretched zones and almost destroyed abutment areas with reinforcement CFRP from carbon fiber sheet Sika® Wrap®-231C according to the established Sika Russie technologies (series 5). The design of this reinforcement is shown in fig. one.

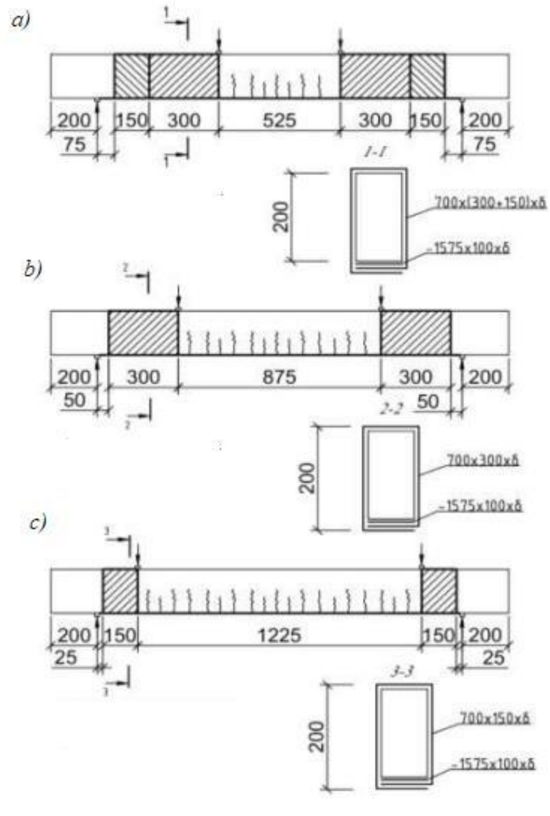

Fig. 1 Diagrams of the tension of the lower stretched zones of the supporting dylanoks of small-sized concrete beams of gray 3 with large (a), middle (b) and (c) spills

Reinforced external tests reinforcement CFRP beams in series 5 were carried out using the same methodology as in series 3 (Karpiuk V.et.al,2017).

RESULTS AND DISCUSSIONS

During testing of prototype beams for the action of short- term single and low-cycle loads, the formation, development and width of crack opening on their surface. Opening width of normal cracks were identified at the level of stretched working reinforcement, and elderly ones - in the middle of the height beams in places where visually it appeared the greatest (V.M. Karpyuk,et.al,2018).

The first to form were normal cracks in the pure bending zone and under concentrated forces at load levels η = 0.15 ... 0.25 of destructive. With increasing load, these cracks developed towards the compressed zone, the width of their opening increased. and new ones were formed in the zone of joint action of the bending moment and shear force with their gradual inclination to the place of application of the concentrated load.

The first oblique cracks appeared at loads η = 0.4...0.6 of the destructive height in the middle in beams with small or medium shear spans or developed from normal cracks in specimens with large shear spans, the maximum amount of transverse and minimum amount of longitudinal working reinforcement .

The developmental process of normal and oblique cracks in beams of the first and third series occurred predictably: with an increase in the magnitude of internal forces, new cracks were formed, the length and width of the opening increased existing cracks, and the further development of these cracks determined the intensity of the transverse reinforcement in the shear spans. At of sufficient amount of destruction of prototypes occurred along normal sections due, as a rule, to the fluidity of the working reinforcement (Baoguo Han,et.al.,2014), and if insufficient, earlier the formed oblique cracks merged into one main or several almost parallel ones, forming a strip along which, in fact, the destruction occurred with possible fluidity of the transverse and longitudinal reinforcement rods and the next shear or crushing of the compressed zone of concrete.
In reinforced outer composite reinforcement beams of the fifth series were observed further development of previously educated and the emergence of new, so-called, secondary, normal cracks in the middle of their part, but completely enveloped in a cloth pivot areas - heal cracks.

Experiments have shown that the opening width normal cracks in the middle of the damaged beams at the load levels specified by the experimental design, on average, 2.2 times higher than that in solid beams of the first and third series.

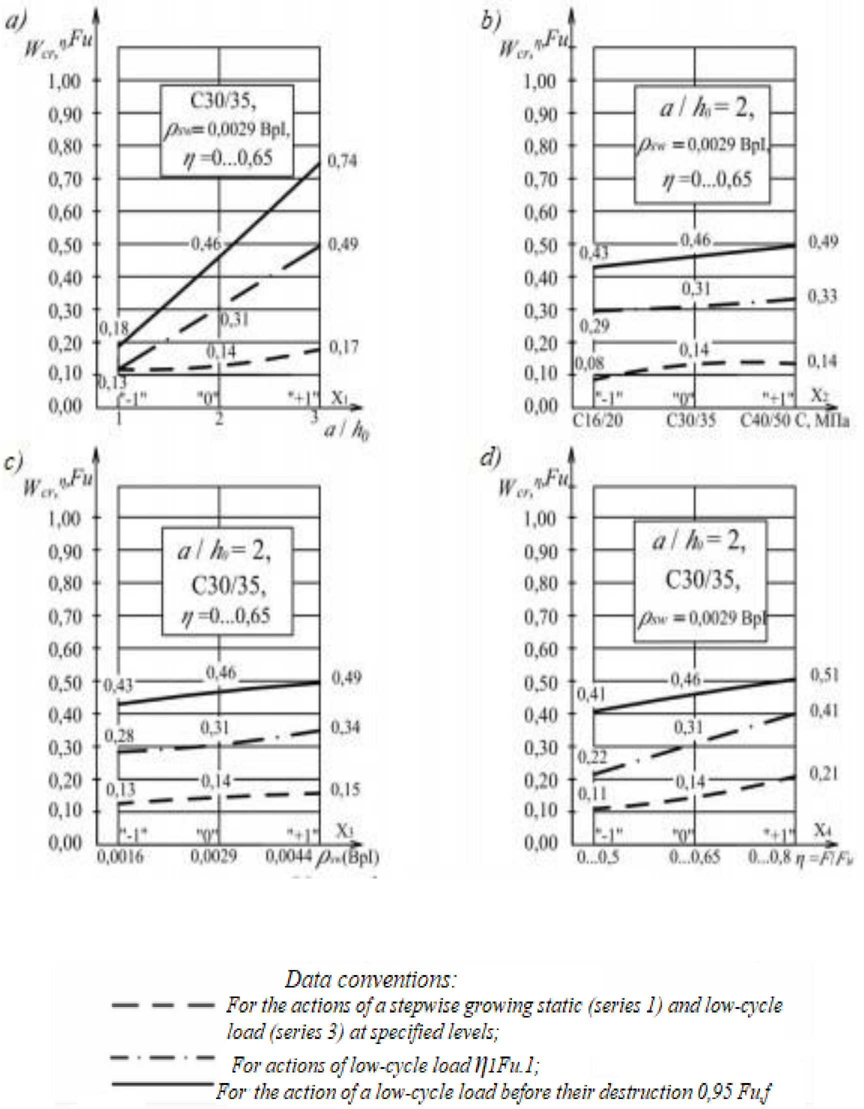

Fig. 2 Influence of the relative span shear a/h0 (a), concrete class C (b), amount of transverse reinforcement ρ_{sw} (c), level of low-cycle reloading η (d), per width of opening ofnormal cracks in the zone A "clean bend" in the middle of the beams at the level of the tensioned reinforcement.

This analysis shows that the maximum width opening of normal cracks in the zone of clean the fold in the indicated series increases compared with the mean value of 0.14, 0.31 and 0.46 mm with average values of research factors: with an increase in the relative span of the cut a/h_0 type 1 to 3 in 29, 116 and 122%; with an increase in the class of concrete from C 16/20 to C 40/50 (actually, to C 30/35) by 43, 13%

- with an increase in the amount of transverse reinforcement ρ_{sw} from 0.0016 to

0.0044 by 14, 19 and 13%;

- with increasing load level η from 0.5 to 0.8F_u by 71 and 58%, and upon reaching η = 0.95 $F_{u,\ f}$ - by 22%;

- simultaneous increase:

- values of the relative span cut and the amount of transverse reinforcement in the specified limits, respectively, at 7, 13 and 13%

- values of the relative span of the cut and the load level by 7%;

- concrete class due to an increase in bearing capacity and load level by 14 and 13% in the fifth series.

Using mathematical planning theory, adopted plan and level changes in design factors and factors external influences allow to apply a systematic approach to studying the phenomena, compare the results obtained between yourself. The loading of prototype beams by concentrated forces (narrow band load) is the most common by the method of testing building structures in laboratory conditions, it makes it possible to predict the area of occurrence of inclined and normal cracks, separating them, it is rational to arrange measuring instruments.

The presence of external carbon fiber reinforcement in the lower tensile zone of the beams in series 5 and on their bearing areas allows you to increase their bearing capacity when this, the average value of the opening width normal cracks in the "pure bend" zone increases from 0.31 to 0.46 mm. at small span of the cut (a/ h0 = 1), all prototypes-beams collapsed in the support areas along oblique cracks or stripes with delamination of the carbon fiber sheet, with medium and large shear spans (a / h0 = 2 or 3) an increase in the amount of external composite reinforcement in these areas leads to, as generally destroying research elements along normal sections in the zone of "clean bending ", which is accompanied by the fluidity of stretched metal and composite reinforcement and the achievement by concrete of the compressed zone of ultimate deformation. At the same time, the maximum width of the opening of normal cracks increased from 0.49 mm in conventional beams of series 3 up to 0.74 mm in CFRP-reinforced elements.

The maximum opening width of normal cracks with a change in the concrete class within the specified limits and the average value of other design factors increases from 0.33 mm in conventional beams up to 0.49 mm in reinforced elements with an increase in the class of concrete within the specified limits.

With an increase in the number of steel transverse reinforcement, the opening width of normal cracks also increase by 15% reaches maximum values from 0.33 to 0.49 mm, in reinforced beams with an average value of other design factors. Changing low-cycle lateral load levels increases the opening width of normal cracks in conventional beams by 60%, and in reinforced beams by 22%, with average values of design factors.

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