UDK 691.175.3

STRESS-STRAIN STATE OF CONCRETE BEAMS WITH BASALT-PLASTIC REINFORCEMENT

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Abstract. The presented results of complex experimental studies of the bearing capacity, deformability and crack resistance of reinforced concrete and basalt concrete beams at high levels of static and low-cycle loads.

Introduction. In recent years, structures with non-metallic composite reinforcement (FRP) have been increasingly widely used in construction, especially in buildings and structures for special purposes.

Due to its high strength, resistance to chemical and physical corrosion, dielectric and dimagnetic properties, low weight and low thermal conductivity, FRP is increasingly replacing steel reinforcement. However, the wider use of FRP for reinforcing concrete structures is constrained by insufficient study of the features of their work, limited regulatory support and little experience in operating the corresponding facilities.

Based on the above, carrying out experimental and theoretical studies of the bearing capacity of structures reinforced with basalt-plastic reinforcement, in order to accumulate a data bank, improve existing and develop new regulatory documents that would make it possible to more widely use such reinforcement in these areas of construction of special-purpose facilities is urgent task.

Isolation of previously unresolved parts of a common problem. The main regulatory documents and recommendations for the calculation of structures made of FRP have been developed in the USA, Canada, Japan, Great Britain, Italy over the past 23 years on the basis of the norms for the calculation and design of reinforced concrete structures made of steel reinforcement. In Ukraine and Russia, respectively, Guidelines and Appendix L to the SP have been prepared, which can be considered as drafts of future regulatory documents. The use of basalt-plastic reinforcement BFRP is not yet sufficiently standardized.

The purpose of the work and the objectives of the research. The purpose of this work is to experimentally study the strength, crack resistance and deformability of basalt concrete beams reinforced with BFRP, and to create an appropriate databank for the further development of physical and mathematical models of the bearing capacity of normal and inclined sections of concrete spans reinforced with BFRP, taking into account the action of static and low-cycle loads. high levels by analogy with similar models developed for reinforced concrete structures.

Research Objective – to investigate the stress-strain state, the nature of destruction, the bearing capacity, the width of the opening of normal cracks and deflections of girder basalt concrete elements in the process of their static and low-cycle load using the theory of experimental planning;

Experimental technique, materials and equipment. In connection with the above, the Odessa State Academy of Civil Engineering and Architecture conducts systemic experimental studies of the bearing capacity of the bearing sections of folding reinforced concrete beam structures.

To achieve this goal, two series of field experiments were additionally implemented with single-span beams reinforced with BFRP, for the actions of static and low-cycle re-loading of high levels

The prototypes were made according to the trifactorial three-level D-optimal plan of Box B3, which provides the same accuracy of forecasting the output parameter in the region described by the radius equal to the conditional "1" relative to the "zero" point.

The following factors (constructive factors) were selected as research factors. Which changed at three levels: X_1 – the relative span of the cut (distance from the support to the concentrated force), a/h_0 = 1, 2, 3 at h_0 = d = 175mm; X_2 – concrete class C, MPa, C16/20, C30/35, C40/50; X_3– coefficient of transverse reinforcement ρ_{fw} (АКБ-800) = 0.0029; 0.0065; 0.0115 for basalt concrete beams and ρ_{sw} (ВрІ) = 0.0016; 0.0028; 0.0044 for reinforced concrete samples. Coefficients of upper and lower longitudinal reinforcement ρ_{lf}=ρ_{ls}=0.0176 for both types of beams with design spans L_0=9h_0=1575 mm. and width b = 100mm.

Each experiment in the field experiment was provided with two twin beams with four supporting sections. For comparison, the results of tests of similar reinforced concrete beams were used.

The prototypes – basalt concrete beams were reinforced with BFRP in the form of two flat knitted frames. For the manufacture of these elements, heavy concrete of the above classes was used on granite crushed stone of fractions of 5-10 mm and quartz sand with a fineness module of 1.5. Portland cement grade 500 without additives was used as a binder.

For testing prototype beams, special power plants were designed, manufactured and certified. The deformations of the concrete of the prototypes were measured using wire and foil strain gauges with a base of 40 and 50 mm. The control over the deformations of the concrete in the compressed zone and tensioned reinforcement was carried out using dial indicators, and vertical displacements - deflection meters.

Presentation of the main material and results. Deformation, cracking and destruction of research basalt concrete and reinforced concrete beams occurred according to the rules of structural mechanics and was predictable. Normal cracks appeared first in the zone of action of maximum bending moments. With a further increase in the transverse load, normal cracks developed deep into the beam, their opening width increased, and new normal cracks appeared. Subsequently, the first oblique cracks appeared. A further increase in the load led to the development of normal and oblique cracks with the predominant opening of oblique cracks to failure behind dangerous oblique cracks.

As a result of the experimental data obtained, the extraction of insignificant and recalculation of those coefficients remained, with the help of the effective computer program COMPEX, adequate experimental-statistical dependences of the main parameters of the performance of prototypes were obtained, which have good informational utility and show good convergence with experimental data.

Strength (bearing capacity) of research elements.

Can be described by the following dependencies

$$\hat{Y}(V_{us}) = 98 - 41x_1 + 12x_2 + 6x_3 + 16x_1^2 - 7x_2^2 - 5x_3^2 - 7x_1x_2, \text{кН}, \quad \mho = 5{,}1\%; \tag{1}$$

$$\hat{Y}(V_{us}^{cyc}) = 90 - 36x_1 + 10x_2 + 7x_3 + 18x_1^2 - 6x_2^2 - 6x_3^2 - 8x_1x_2, \text{кН}, \quad \mho = 5{,}1\%; \tag{2}$$

$$\hat{Y}(V_{uf1}) = 51{,}8 - 30{,}1x_1 + 11{,}8x_2 + 5{,}5x_3 + 15{,}9x_1^2 - 5{,}5x_2^2 - 2{,}3x_3^2 - 10{,}6x_1x_2 - 4{,}8x_1x_3, \text{кН}, \mho = 5{,}0\%; \tag{3}$$

$$\hat{Y}((V_{uf2}^{cyc}) = 44{,}3 - 27{,}0x_1 + 10{,}4x_2 + 4{,}5x_3 + 17{,}3x_1^2 - 4{,}0x_2^2 - 2{,}4x_3^2 - 10{,}2x_1x_2 - 2{,}9x_1x_3, \text{кН}, \mho = 5{,}5\%, \tag{4}$$

where V_{us}, V_{us}^{cyc}– breaking shear force, respectively, under static and low-cycle re-loading of reinforced concrete beams from ;

V_{uf1}, $V_{uf2}^{\boldsymbol{cyc}}$– breaking shear force, respectively, under static and low-cycle reloading of concrete beams reinforced with BFRP, with the same values of design factors.

The presented adequate experimental-statistical dependences (1)...(4), named by prof. Voznechensky V.A. mathematical models, have a significant advantage over correlation and other dependencies in that they allow a comprehensive assessment of the influence of each of the above factors on the determining output parameters, not only in particular, but also in interaction with each other, and also to compare the magnitude of this influence as on reinforced concrete beams and concrete elements reinforced with BFRP, for the actions of stepwise increasing static and low-cycle reloading. The geometric interpretation of the bearing capacity of the supporting sections of the prototype beams is partially shown in Fig. 1.

Among the design factors, the relative span of the cut has the greatest influence on the bearing capacity of the bearing sections of the research elements (Fig. 1, a). In general, it is confirmed that A.S. Zalesov, Yu.A. Klimov, V.M. Karpyuk and other researchers the regularity of decreasing the strength of inclined sections of beams reinforced with both steel and basalt (BFRP) reinforcement, with an increase in the shear span according to a nonlinear law.

The next largest influence is the concrete class. At the same time, with an increase in the class of concrete from C16/20 to C30/35, the bearing capacity of inclined sections grows more intensively.

A similar picture is observed with an increase in the transverse reinforcement coefficients $\rho_{sw}, \rho_{\boldsymbol{fw}}$.

The analysis of dependencies (1)...(4) shows that they are qualitatively of the same type and the influence of design factors, as well as the factor of low-cycle reloading, is qualitatively similar. The differences are observed in quantitative terms.

So, the bearing capacity of inclined sections of prototypes-beams, expressed through the destructive shear force V_u, increases in relation to their average values (free members b_0), respectively, 98; 90; 51.8; 44.3:

- with a decrease in the relative span of the cutoff $a/h_0$from 3 to 1 in the indicated series, respectively 84%, 80%, 116%, 122%;
- with an increase in the class of concrete from C16 / 20 to C40 / 50, respectively, by 24%, 22%, 46% and 47%;
- with an increase in the amount of transverse steel reinforcement ρ_{sw} from 0.0016 to 0.0044 (expressions (1), (2) and basalt-plastic BFRP $\rho_{\boldsymbol{fw}}$ from 0.0029 to 0.0115, respectively, by 12%, 16%, 21% and 20%;
- with a simultaneous decrease in the relative span of the cut $a/h_0$and an increase in the class of concrete C, respectively, by 7%, 9%, 20% and 23%;
- with a simultaneous decrease in the relative shear span $a/h_0$and an increase in the amount of transverse basalt-plastic reinforcement ρ_{fw}, respectively, by 9% and 7%.

Due to the significantly higher deformability (4.44 times), the replacement of steel reinforcement with basalt-plastic BFRP, all other design factors being equal, led to a decrease in the breaking shear force V_u under a static load of prototypes-beams, on average, by 47%, and with a low-roll reinforcement – by 51 %. It is characteristic that such a decrease in their bearing capacity is inherent in the entire range of changes in design factors (Fig. 1).

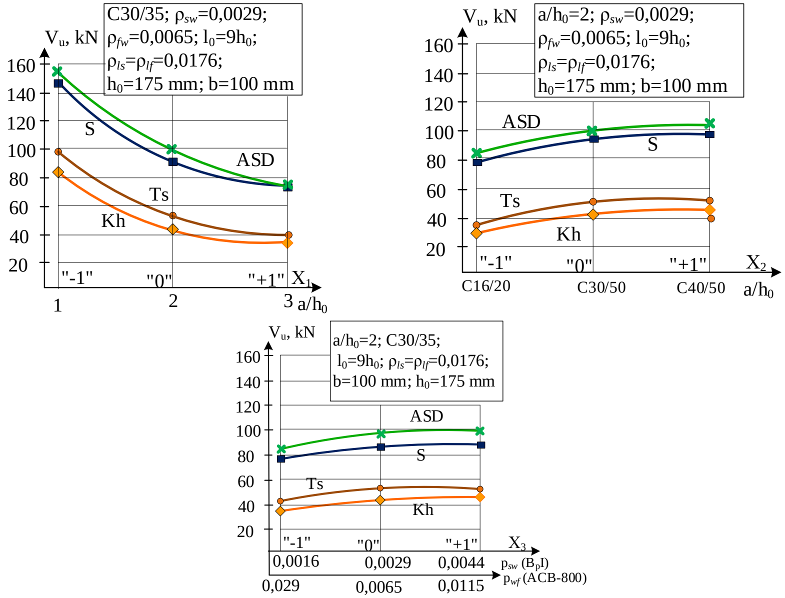

Fig. 1. The influence of design factors on the bearing capacity of the supporting sections of the research elements: *a* – the relative span of the slice; *b* – the class concrete; *c* – the number of transverse reinforcement; ASD – according to; S – according to; Ts – in the experiments of A. Tselikova; Kh – in the experiments of A. Khudobych.

Low-cycle reloading reduces the bearing capacity of the bearing sections of reinforced concrete beams, on average by 8%, which is confirmed by numerous works of professors EM Babich, G.Kh. and their students, and concrete elements reinforced with BFRP turned out to be 14% higher.

Absolutely most of the research beams collapsed along inclined sections in both or one (more often) of the cut spans. The criterion for the destruction of prototypes was the achievement of ultimate deformations in concrete or reinforcement with clear signs of plastic deformations in them, excessive opening (up to 1 mm or more) of oblique (more often) or normal (less often) cracks, a significant increase in the deflection arrow ($f \geq \frac{1}{100} l_0$), no increase or some decline (up to 15%) in the pressure gauge display of the power plant pumping station.

Obviously, the main reason for the decrease in the bearing capacity of the prototypes under low-cycle reloading is the violation of the structure of concrete, especially in the support areas, its loosening and partial loss of adhesion to the reinforcement.

Non-reinforcement (ρ_{sw}≤0.003(BpI), ρ_{ls}≤0.018(A500C)) reinforced concrete prototypes-beams with stepwise growing static and low-cycle repeated loads, as a rule, collapsed according to the B/M scheme, that is, by inclined sections with the overwhelming action of the bending moment due to the fluidity of the longitudinal working reinforcement at the mouth of a dangerous inclined crack and transverse reinforcement is crossed by it.

Conclusions:

1. A systematic approach to the experimental and theoretical study of the stress-strain state of beam structures reinforced with steel and basalt-reinforced plastic (BFRP) reinforcement was implemented, for the first time it made it possible to make a reliable quantitative and qualitative assessment of the influence of design factors and external factors on their bearing capacity, stiffness, crack resistance and other parameters operability, in particular, and in interaction with each other, it is essential to clarify the physical model of the operation of these structures with their statistical and low-cycle repeated loading. In particular, it was found that the strength of research elements increases nonlinearly:

- with a decrease in the value of the relative span of the cut $a/h_0$from 3 to 1 in the indicated series by 80...122%;
- with an increase in the concrete class from C16/20 to C40/50 by 24...47%;
- with an increase in the number of transverse reinforcement $\rho_{sw}$from 0.0016 to 0.0044 and basalt-plastic $\rho_{fw}$from 0.0029 to 0.0115, respectively, by 12...16% and 20...21%;
- at the same time, the relative span of the cut and the increased class of concrete are reduced by 7...23%;
- simultaneously reduced a/h_0 and increased $\rho_{fw}$by 7...9%.

2. Replacing steel reinforcement with a more malleable basalt-plastic BFRP, all other design factors being equal, leads to a decrease in the bearing capacity of inclined sections of prototypes - beams with their static load, on average, by 47%, and with low-cycle reuse – by 51%.

3. Low-cycle reloading reduces the bearing capacity of the supporting sections of reinforced concrete beams by an average of 8%, and of concrete elements reinforced with BFRP – by 14%.