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STRENGTH OF REINFORCED WITH BASALT-PLASTIC REINFORCEMENT BEAMS

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Abstract. The experimental data on the strength, deformability and crack resistance of reinforced concrete and basalt concrete beams 200x200x100mm in the form of experimental-statistical dependencies are presented. The longitudinal reinforcement of reinforced concrete beams is 2Ø14A500C, and the basalt concrete reinforcement is 2Ø14BFRP (AKB800). The transverse reinforcement of reinforced concrete beams was 2Ø3, 4, 5BpI, basalt concrete – 2Ø4, 6, 8BFRP (AKB800). Beams were made of heavy concrete of classes C16/20, C30/35 and C40/50. The prototypes were tested according to a four-point scheme as freely supported beams loaded with two concentrated forces. The load in the series of experiments was one-time stepwise rising, and also several times repeated at 0.50 levels; 0.65; and 0.80F_{ult}. The distance from the supports to the concentrated forces (shear span), a/h_0, was varied within 1, 2, 3. The beams were made and tested in accordance with the theory of experimental planning. From this theory, the D-optimal Box B_4 plan was used.

Relevance. During recent decades the structures with non-metallic composite reinforcements (NCR) find the ever growing use in the construction practice, particularly in the special purpose buildings and facilities. Due to high strength, resistance to physical and chemical corrosion, dielectric and diamagnetic properties, little weight and low heat conductivity, the NCR replace steel reinforcement increasingly frequently. However, a wide use of the NCR for reinforcing concrete structures is hindered by insufficient study of the peculiarities of their performance, inadequate regulatory support and scant experience of operating the appropriate facilities.

Experience has shown that the use of NCR is promising and economically justified when constructing roads, hydrotechnical and transport facilities, erection of bridge spans, treatment facilities, chemical installations and food industry facilities as well as special purpose buildings and arrangement of foundations in corrosive soil environment. At that, the application prospects of the basalt plastic reinforcement is explained by low cost of the main raw material – basalt fibre as far as by the fact that in the world there are considerable deposits of basalt which has unique physical and chemical properties, specifically, the better chemical resistance to corrosive environment as compared with the fiber-glass reinforcement. The foregoing determines the relevance of research in this direction.

Easy-to-extract basalt deposits have been explored in Ukraine and a number of plants in Kharkiv and Khmelnytskyi regions already produce high-quality basalt plastic reinforcement. It is characteristic that production of such reinforcement is less hazardous for the environment than the use of steel reinforcement. Proceeding from the above, it is a topical task to perform experimental and theoretical research of the load-bearing capacity of the structures reinforced with basalt-plastic in order to accumulate the database and improve the existing and develop new regulatory documents that enable to a wider application of such reinforcement in the indicated spheres of special facility construction. The above is an important scientific and technical problem.

Definition of the earlier unresolved parts of the general problem. The main normative documents and guidelines dealing with calculation of the structures with NCR have been developed in the USA, Canada, Japan, Great Britain and Italy for the last 23 years on the basis of the standards for calculation and design of the steel reinforced concrete structures. In Ukraine and Russia the developed are, accordingly, the Guidelines [1] and Annex Л to SP [2] which can be considered as the drafts of future normative documents.

The main principles governing the calculation have been preserved the same as for the reinforced concrete structures with due account of the linear performance of the NCR. Specific performance of the NCR-containing structures is taken into account by introduction of special decreasing coefficients that characterize work conditions and the standardization of the material characteristics. The formulae for determination of the design parameters of the NCR-containing structures repeat, on the whole, the formulae applied for the structures with steel reinforcement. Still, in the majority of cases the design requirements have been taken more cautious as compared with the reinforced concrete structures. The aspects pertaining to the standardization of the requirements to fiber-glass, organic plastic and carbon fibre reinforcement have been studied to a greater extent. Application of the basalt plastic reinforcement is still not quite standardized.

Based on the analysis of the results obtained when studying chemical resistance, physical and mechanical properties and the practical experience of the CR application, it is evident that it is expedient to use the BFRP in civil and road construction, in hydrotechnical structures and in the facilities that necessitate special requirements. Comparison of the published test data with the calculated results of the load-bearing capacity of basalt-fibre reinforced structures made according to the effective domestic and foreign standards as well as to the authors' methodologies proves, on the whole, their poor convergence. At that, as the above mentioned analysis has shown, the lion's share of the publications deals with determination of the load-bearing capacity of the normal cross-sections of NCR structures according to the first and second groups of boundary conditions while the study of strengths of the inclined cross-sections still remains in an embryonic state and remains, practically, not addressed.

Goal of the work and tasks of the study. This work is aimed at experimental study of strength, crack resistance and stress-strain behaviour of the BFRP concrete beams and establishment of the appropriate databank for further development of the physical and mathematical models of the bearing capacity of the normal and transverse cross-sections of the BFRP spanned concrete structures with due account of the action of static and low-cycle high level loads by analogy to similar models [5] that have been developed for the reinforced concrete structures.

The tasks of the study:

- to investigate the stress-strain behaviour, the nature of collapsing, load-bearing capacity, width of the normal cracks and sags of basalt fibre reinforced concrete elements in the course of their static and low-cycle loading with the use of the experimental design theory;
- to study the impact of the main design factors on the load-bearing capacity of the support zones of the studied elements, their crack resistance, and stress-strain behaviour with the aid of experimental and statistical dependencies obtained in the course of processing the obtained data;
- to make a comparative analysis of the impact of the main design factors on said parameters of the similarly reinforced with steel and BFRP test beams with due account of the static and low-cycle loading.

Materials and methods. In connection with the above, the system experimental research [3-5] of the load-bearing capacity of support zones of complex loaded reinforced concrete beam structures are being performed in Odesa State Academy of Construction and Architecture.

To achieve this goal two more series of field studies were additionally accomplished by testing single-span BFRP concrete beams subjected to static and low-cycle repeated loads of high level in accordance with the central government budget research projects (state registration №0107U000809 and 0108U000559) with the use of the experimental design theory and efficient PC COMPEX of prof. V.A. Voznesenskyi.

It is known from literary sources that the main performance parameters of steel, fibre and basalt fibre reinforced concrete structures are governed by the Gaussian law and that it is possible to process the results with the least square method. As the studied factors can influence the output function in a non-linear manner, it is expedient to approximate it with the second order polynomial. That is why the test samples were prepared with the use of the three-factor three-level D-optimum Box plan B3 [6] which ensures the same accuracy of the output parameter prediction within the area that is described with the radius that equals the conventional “1” with respect of the “zero” point.

The following factors (design factors) were chosen as the test ones that were changing at three levels: X_1 – relative shear span (distance from the support to the concentrated force), a/h_0 = 1,2,3 at h_0 = d = 175 mm; X_2 – the concrete grade C, MPa, C16/20, C30/35, C40/50; X_3 – transverse reinforcement coefficient ρ_{fw} (ACB-800 (composite basalt-plastic reinforcement)) = 0.0029; 0.0065; 0.0115 for basalt fibre reinforced concrete beams and ρ_{sw} (BpI) = 0.0016; 0.0028; 0.0044 for the reinforced concrete samples. Coefficients of the upper and low longitudinal reinforcement ρ_{lf}=ρ_{ls}=0.0176 for both beam types with the design spans L_0=9h_0=1,575 mm and width b=100 mm.

Each study of the field test provided for two twin beams having four support areas. Altogether there were tested 30+30=60 basalt concrete beams subjected to, accordingly, stepped increase of the static and low-cycle repeated loading. For the sake of comparison, we used the test results of similar reinforced concrete beams [5]. The tested beams were reinforced with basalt fibre plastic in kind of two flat tied frames. These elements were produced with the use of heavy concrete of the above indicated grades plus the 5-10 mm granite chips and 1.5 mm fineness modulus quartz sand. Portland cement grade 500 without additives was used as a binder. In order to reduce the water/cement ratio, make it more convenient to place concrete mix and shorten the cure period, all tests were conducted with Relaxol-Super M (ISO 9001 №04.156.26) complex additive in quantity of 1% of the cement weight as recalculated to dry substance.

Special power installations were designed, manufactured and certified for testing the sample beams. Loads were applied according to the four-point scheme with the aid of the DG-50 hydraulic jack and the load distribution traverse beam; the concentrated forces were applied in stages: with the step (0.04…0.06) F_{ult} until appearance of the first normal and inclined cracks, and afterwards with the step (0.08…0.12) F_{ult} until rupture. The time exposure on a step was up to 15 minutes, and all measurements were made at the beginning and at the end of each step. Before making the test beams, chains of KF5P1-5-200 strain gauges were glued on the tensioned reinforcement of one of the flat frames (base 5mm) in compliance with the technology recommended by the manufacturer ("Veda", Kyiv).

Deformation of the test concrete samples were measured with the aid of wire and foil strain gauges with the 40 and 50 mm base according to the generally adopted methodology; the strain gauges were glued on one lateral and the top polished sides. The transfer from the strains of the reinforcement measured during testing was accomplished according to Hooke law, and the strains in the concrete were measured through the sectional elasticity modulus. Deformations of the concrete located in the compressed zone and in the tensioned reinforcement were checked with the aid of the dial gauges and the vertical displacements were measured with deflection indicators.

Statement of basic materials and results. Deformation, cracking and destruction of the tested basalt fibre reinforced beams and reinforced concrete beams occurred in accordance with the construction mechanics rules and was predictable. The normal cracks were the first to appear within the zone of the maximum bending moments. As the transverse loading increased, the normal cracks developed deeper in the beam, their widths also increased and new normal cracks were appearing. Then new normal cracks appeared. The further increase of loading has led to the development of normal and inclined cracks with the prevailing opening of the inclined cracks until rupture took place along the dangerous inclined cracks.

The tested beam samples were designed almost of equal strength in the normal and inclined cross-sections, however, they were made so that their collapse was still taking place in along the inclined cracks under action of the collapsing transverse forces and the associated bending moments at the final stage of beam performance.

On the basis of the obtained test data, removal of the insignificant coefficients and re-calculation of the remaining coefficients, the adequate experimental and statistical dependencies of the main test sample performance parameters were obtained with the aid of the efficient computer software program COMPEX. This data presents a good and useful information and show good convergence with the test data.

Strength (load-bearing capacity) of the studied elements

It can be characterized by the following dependencies:

$$\hat{Y}(V_{us}) = 98 - 41x_1 + 12x_2 + 6x_3 + 16x_1^2 - 7x_2^2 - 5x_3^2 - 7x_1x_2, \kappa H, \qquad \mho = 5.1\% \tag{1}$$

$$\hat{Y}\left(V_{us}^{cyc}\right) = 90 - 36x_1 + 10x_2 + 7x_3 + 18x_1^2 - 6x_2^2 - 6x_3^2 - 8x_1x_2, \kappa H, \qquad \mho = 5.1\% \tag{2}$$

$$\hat{Y}\left(V_{uf1}\right) = 51{,}8 - 30.1x_1 + 11.8x_2 + 5.5x_3 + 15.9x_1^2 - 5.5x_2^2 - 2.3x_3^2 - 10.6x_1x_2 - 4.8x_1x_3, \kappa H, \quad \mho = 5.0\% \tag{3}$$

$$\hat{Y}\left((V_{uf2}^{cyc}\right) = 44.3 - 27.0x_1 + 10.4x_2 + 4.5x_3 + 17.3x_1^2 - 4.0x_2^2 - 2.4x_3^2 - 10.2x_1x_2 - 2.9x_1x_3, \kappa H, \quad \mho = 5.5\% \tag{4}$$

where, V_{us}, V_{us}^{cyc} – collapsing transverse force at, accordingly, static and low-cycle repeated loading of reinforced concrete beams according to [5];

V_{uf1}, V_{uf2}^{cyc} – collapsing transverse force at, accordingly, static and low-cycle repeated loading of the BFRP concrete beams at the same values of the design factors.

Conclusions. The accomplished system approach to the experimental and theoretical study of the stress-strain behaviour of beam structures reinforced with steel and basalt-plastic (BFRP) enabled, for the first time, to perform reliable quantitative and qualitative evaluation of the impact of design factors and external factors on their load-bearing capacity, stiffness, crack resistance and other performance parameters taken both individually and in interaction with each other, to considerable specify the physical model of how said structures work when subjected to static and low-cycle repeated loading.

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