Consideration Of The Effect Of Low-Cycle Loads On Bended Concrete Beams Reinforced With Basalt-Plastic Armature

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***Abstract*—The research results of beam bended basalt-concrete and basalt-fibrous concrete elements under the influence of one-time static and low-cycle loads are presented. The use of basalt-plastic armature for the reinforcement of concrete structures has a significant aspect. The cyclic loads influence on road bridges including low-cycle loads of a high level. There were tested 48 beams from heavy concrete and concrete with basalt fiber. Beams had a different percentage of reinforcement. As a result of the study it was found that low-cycle (on the basis of 10 cycles) loads of 0.6 and 0.75 levels from the destructive load do not affect the bearing capacity of the beam bended basalt concrete and basalt-fibrous concrete elements. The increase in the width of the opening of cracks and the growth of deflections under the influence of low cycle loads is proposed to be taken into account by introducing known formulas for calculations of empirical coefficients determined as a result of the research data analysis.**

Keywords - nonmetal composite reinforcement, basalt, fiber concrete.

I. INTRODUCTION

Bridges in Ukraine, as well as abroad, are mostly built from reinforced concrete. But there are defects in reinforced concrete bridges during the operation that reduce their bearing capacity. The most common defect, which greatly affects the condition of bridges, is corrosion of steel fittings [1].

The steel reinforcement under the influence of moisture is corroborating and its bearing capacity is decreasing and losing. The product of iron corrosion is rust; it is a complex mixture of variable composition, which takes a much larger volume in 2-7 times than the initial volume of iron itself. The great efforts are developed in the formation of rust that causes the appearance of cracks in concrete, and then cracking the protective layer.

The environment in concrete is alkaline at the beginning of the use of reinforced concrete structures and it contributes to passivation of the surface of the reinforcement and protects it from the influence of the external environment. After interacting with carbon dioxide, sulfur and other gases in the atmosphere, the pH index of the concrete is decreased to values when the corrosion of the reinforcement in the concrete body begins [2]. The conditions of operation of reinforced concrete bridges and chlorination of concrete become worse as a result of anti-icing treatment of coatings, and weakly acidic precipitation from atmospheric pollution by industrial enterprises [3].

In Ukraine, the following design terms for the service of reinforced concrete bridges are established: 70 years for collective, 80 for collective and monolithic, 100 years for monolithic structures [3]. But the experience of bridge operation shows that in fact, the terms of a significant number of bridges do not exceed 50 years in our country [1].

Similar problems in the operation of reinforced concrete bridges are observed in other countries. For example, in Japan, the Ministry of Finance established a life cycle of reinforced concrete bridges in 60 years [4].

The use of non-metal composite armature for the reinforcement of concrete bridge structures is perspective. In many countries the various structures, including bridges, were designed, constructed and operated for many years [5; 6]. The main advantages of non-metal composite reinforcement are corrosion resistance, high strength, low specific gravity, dielectricity.

Non-metallic composite fittings depending on the type of used fibers can be fiberglass plastic, basalt-plastic, organoplastic, carbon-plastic. In different countries, physical and mechanical characteristics of non-metallic composite reinforcement and works under a load of concrete elements being reinforced with such armature were investigated [7; 8]. A number of countries have developed regulatory documents. In Europe, the design of concrete structures being reinforced with non-metallic composite reinforcement is carried out in accordance with the Fib principles [9; 10].

Basalt-plastic reinforcement has better physical and mechanical qualities than fiberglass and is substantially cheaper than carbon-plastic one. Research of concrete beams reinforced with basalt-plastic armature showed that the basalt-plastic reinforcement of the periodic profile is reliably included in the joint work with concrete and where the beams were destroyed by a moment or transverse force. Some studies of the coupling of basalt-plastic reinforcement from a periodic profile with concrete have shown that such fittings on the characteristics of the coupling are comparable to steel reinforcement [11; 12].

In Ukraine, there are significant basalt deposits and there are factories that produce basalt-plastic reinforcement. Under the guidance of Professor Yu. Klimov it was carried out the comprehensive research on basalt-plastic reinforcement and beam bended concrete elements being reinforced with such armature. On the basis of these studies, Ukrainian norms were developed [13] and using them the concrete structures being reinforced with basalt-plastic armature can be designed.

As you know, bridges undergo the effects of cyclic loads. During the operation, the bridge structures experience the effects of millions of cycle loads of the level up to 0.3-0.4 % from the destructive one. Low-cycle loads up to 0.6-0.75 from the destructive one also influence on the construction of bridges. Such loads include passing through bridges the over normalized heavy vehicles, full-scale tests and other cases. In the studies by P. Koval and R. Paliuha, the levels and the number of low-cycle high-level loads for bridges that were operated on Ukrainian roads were established [14].

The work of concrete structures reinforced with basalt-plastic armature under the influence of cyclic loads has not been investigated yet. Therefore, the purpose of these studies was to determine the effect of high-level low-cycle loads on the work of beam bended basalt concrete elements.

II. EXPERIMENTAL PROGRAM SCHEME

The research program included testing 48 beams (Table 1). They were divided into two groups. The first group of beams, 12 basaltic concrete and 12 basalt-fibrous concrete beams, was tested for one-time static loads. These were the basic samples for comparison (marking BO – a beam for one-time loads and BOf – a beam for one-time loads using basalt fiber). The second group of beams, similar to 12 basaltic concrete and 12 basalt-fibrous concrete beams, was tested on low-cycle loads of high level (marking BL – a beam for low cycle loads and BLf – a beam for low cycly loads using basalt fiber).

Table 1. Test program

Series	**Work reinforcement ; reinforcement coefficient;**	**One-time loads**		**Low cycle loads**	
		sample Marking	Number of beams	sample Marking	Number of beams
I	1∅4RNPB 0,00073	I-BO	2	I- BL	2
		I-BOf	2	I- BLf	2
II	1∅6RNPB 0,00158	II-BO	2	II- BL	2
		II-BOf	2	II-BLf	2
III	1∅8RNPB 0,00286	III-BO	2	III-BL	2
		III-BOf	2	III-BLf	2
IV	1∅10RNPB 0,00446	IV-BO	2	IV-BL	2
		IV-BOf	2	IV-BLf	2
V	1∅12RNPB 0,00649	V-BO	2	V-BL	2
		V-BOf	2	V-BLf	2
VI	1∅13RNPB 0,0077	VI-BO	2	VI-BL	2
		VI-BOf	2	VI-BLf	2

A. TEST SAMPLES

Experimental samples were beams of a cross section of 100x200 mm and with a length of 2100 mm (Fig. 1), which were made of concrete of the class B40. The beams were of heavy concrete (marking (BO and BL) and of heavy concrete with basalt fiber (marking (BOf and BLf). The frameworks of the beams consist of one rod of working reinforcement with diameters 4, 6, 8, 10, 12 and 13 mm of basalt-plastic reinforcement RNPB (Fig. 1). In the extreme third of the run, a cross-section was done by reinforcement of ∅ 6 mm of class A-I with a length of 180 mm. The step of cross-sectional rods was 100 mm; the total number of rods of transverse reinforcement was 16 pcs. The upper reinforcement was made by the rods ∅ of 6 mm of grade A-1 with a length 730 mm in the extreme third of the run. Coefficients of the reinforcement of the cross section in the structure (ρf,tot) is 0.00073; 0.00158; 0.00286; 0.00446; 0.00649; 0.0077.

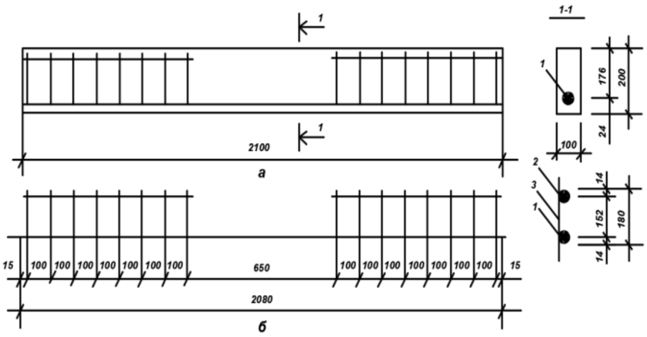

Fig.1 Design of basalt concrete beams (a) and beams frames (b):

1-1∅(4; 6; 8; 10; 12; 13) RNPB; 2-2∅6A-I; 3-16∅6A-I

B. Method of testing

The tests were carried out on a power stand (Fig. 2) by two centered forces located in thirds of the run according to the net bending scheme. Fiber deformations of concrete at a beam height in the middle of a run were measured by indicators with a scale division of 0,001 mm on the basis of 200 mm and by tensor resistors on the basis of 50 mm in the complete set with the measuring device AVD 4M. The deflection of the beams and the precipitate of the supports were measured by the Aistov PA06. The width of the opening of the crack was determined using a microscope MPB-2 and a scale division of 0.05 mm.

Fig. 2 Investigation of the stress-strain state of

bending structures reinforced with composite armature

The basis for assessing the work of prototype beams on low cycle loads were data obtained from tests of similar beams tested on single loads.

For our study the number N=10 cycles (Fig. 3) was adopted for the low cycle loads, the number and the levels are based on the research [15]. The values of the destructive load Pcr were determined on the twin beams at one-time static load. The base level of the cyclic load was taken 0,6 Pcr., to which the samples were proved with loads to the level of 0.75 Pcr.

In order to model the loading of the structure to a higher level, after the first six cycles with a maximum load level of 0.6 Pcr, at the seventh and eighth cycles, the load level was brought to 0.75 Pcr. The 9th cycle was carried out with a maximum load of 0.6 Pcr, the tenth one – again to 0.75 Pcr. After the test base, the beams were brought to the destruction by one-time force attempt with the fixing of the damaging load. Load levels were assigned according to the parameters of the work cycles of road bridges, which on average are ηtop = 0,6 . 0,75. The sequence of load levels in cycles is also determined on the basis of observations of the traffic of heavy loads on road bridges.

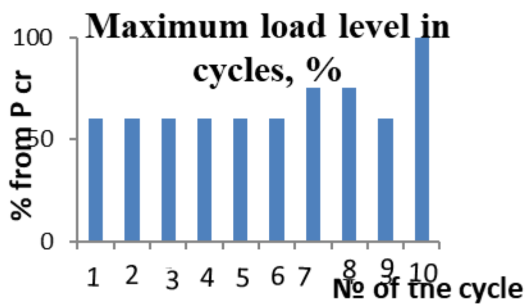

Fig. 3 Scheme of low cycle loads

III Results

The comparison of bending moments, where the basalt concrete beams have been destroyed, shows that the low-cycle loads of a high level did not significantly affect the bearing capacity of the beams. So, for the I-IV series beams the bearing capacity after low cycle loads was higher on 3 - 15.2% from the bearing capacity of beams of single loads. The bearing capacity of the V-VI series beams after low cycle loads was on 2.25 - 13.70% lower than the bearing capacity of beams after single loads. The distribution of the obtained data is within the limits of the allowable values in the experimental studies, therefore it can be argued that the low-cycle loads did not reduce the bearing capacity of concrete beams reinforced with basalt-plastic armature.

The ability of the basalt-fibrous concrete beams after low-cycle loads of a high level is slightly different from the bearing capacity of the basalt-fibrous concrete beams under the action of one-time loads: from 4.5% less to 6% higher bearing capacity.

As a result of the obtained experimental data, it can be concluded that the low-cycle loads (at the base of 10 cycles) of a high level of 0.6 Rcr and 0.75 Rcr do not affect the ability of the beam bended basalt concrete and basalt-fibrous concrete elements, and when they are calculated by the first group of boundary states, such loads cannot be taken into account.

As experimental studies have shown, under the influence of low-cycle loads of a high-level in beam bending basalt concrete structures, the width of crack opening increases and the deflections are growing. Therefore, it is advisable to make additions to the calculations of such structures by the second group of boundary states under the influence of low cycle loads.

The width of the opening of the normal cracks acrc to the longitudinal axis in the beam bended basalt concrete structures of the bridges under the influence of low cycle loads is proposed to be determined by the formula (3.85) [16] using the empirical coefficient that takes into account the effect of cyclic loads:

$$a_{cr} = \psi_{cyc}^{crc} \frac{\sigma}{E} \psi \le \Delta_{cr} \quad \textbf{(1)}$$

where ψ_{cyc}^{crc} – is a coefficient that takes into account the effect of cyclic loads using the table 2;

σ – tensile stress, which is equal to the non-elastic reinforcement of tension δs in the most stretched (extreme) rods of the basalt-plastic reinforcement;

E – modulus of elasticity of basalt-plastic reinforcement;

ψ – the coefficient of crack opening, which is determined depending on the radius of reinforcement (considering the influence of the concrete of the stretched zone, the reinforcement deformations, its profile and operating conditions of the element), adopted in accordance with the article 3.109 [16],

Δ_{cr} – the limiting value of the calculated crack width, which is 0.8 mm [14].

Table 2. The coefficient value ψ_{cyc}^{crc}

Coefficient	Low-cycle load level 0,6 Pcr	Low-cycle load level 0,75 Pcr
ψ_{cyc}^{crc}	1,12	1,5

The empirical coefficient ψ_{cyc}^{crc} is determined by the results of the study of basalt concrete and basalt-fiber concrete beams in accordance with the program of experiments (Table 1). The increase in the width of crack opening due to the effect of low cycle loads in basalt concrete and basalt-fibrous concrete beams was a close value, therefore these data were used for joint processing of results.

The effect of low-cycle loads on the deflections of basalt concrete beams is proposed considering the introduction of the coefficient in formula (3.92) [16] coefficient ψ_{cyc}^{f}

$$f(\alpha) = \psi_{cyc}^{f} \sum \int_0^l \overline{M}(x) \frac{1}{\rho}(x) dx \quad \textbf{(2)}$$

where $\overline{M}(x)$ – is during determining the deflection f – the function of bending moment from the unit force applied in the direction of the desired deflection f, defining the angle of rotation α – the function of a bending moment from the unit moment applied in the direction of the desired angle of rotation;

$\frac{1}{\rho}(x)$ - the curvature of an element in the same section from the load, where a deflection or an angle of rotation is determined (the sign is taken in accordance with the sign of the bending moment in the specified section);

In formula (2), the summation is done in all sections (along the length of the run), which differ in the laws of the change in the quantities $\overline{M}(x)$ and $\frac{1}{\rho}(x)$.

ψ_{cyc}^{f} – the coefficient that takes the effect of cyclic loads and is accepted according to the table 3.

Table 3. The coefficient value ψ_{cyc}^{f}

Coefficient	Low-cycle load level 0,6 Pcr	Low-cycle load level 0,75 Pcr
ψ_{cyc}^{f}	1,11	1,46

The value of the coefficient ψ_{cyc}^{f} was obtained from the experimental data of research of basalt concrete and basalt-fibrous concrete beams under the influence of low cycle loads. The growth of deflections in basalt concrete and basalt-fibrobone concrete beams was close in magnitude; therefore these data were used for joint processing of results.

IV. Conclusion

It was established that low-cycle (on the basis of 10 cycles) loads of a high-level of 0.6 Rcr and 0.75 Rcr do not affect the ability of beam bended basalt concrete and basalt-fibrous concrete elements. Therefore, during the calculation of such beams for the first group of extreme states, they cannot be taken into account.

In the calculation of basalt concrete and basalt-fibrous concrete beams for the second group of extreme states it is proposed to take into account the effect of low-cycle loads of a high level in the following way:.

- to determine the width of the crack opening, it is important to enter the coefficient ψ_{cyc}^{crc}, into formula (1), which during the repeated loads of 0.6 Rcr level is 1.12., at loading level of 0,75 Rcr - 1,5;

- to define deflections, it is necessary to enter into formula (2) the coefficient ψ_{cyc}^{f}, which at repeated loads of 0.6 Rcr is equal 1.11, at a level of 0.75 Rcr - 1.46.

REFERENCES.

[1]Lantukh-Liashchenko A. Strategy for managing the resource of reinforced concrete road bridges. Bridges and tunnels: theory, research, practice, pp. 95-100, 2012.

[2] Pokhmurskui V. I. Protection against corrosion of steel reinforcement damaged by concrete cracks. Collection of scientific works of Ukrainian Institute of Steel Structures named after V. M. Shymanovskyi, Issue 7, pp. 53-63, 2011.

[3] Matchenko T. I. Determination of the degree of aggressive influence of the environment on concrete. Industrial construction and engineering structures, Kyiv, № 1, pp. 22-27, 2015.

[4] Bridges and pipes. Basic design requirements [Text]: DBN V.2.3-22:2009 (state standard), Kyiv, 2009, 73 p.

[5]Matsumoto, T. Survival analysis on bridges for modeling bridge replacement and evaluating bridge performance [Text] / T. Matsumoto. S. S. Beng // Proceeding Japan-Taiwan international workshop on urban regeneration. Maintenance and green material. – 2005. – P. 23-36.

[6]Adel ElSafti,Brahim Benmokrahe, Sami Rizkalla.Degradation Assessment of Internal Continuous Fiber Reinforcement in Concrete Environment: Materials Reseach Report/ - University of Nort Florida. - UNF Projekt Contract No. BDK 82 # 977 - 05. - 2013. - 398p.

[7]Gscheider Alfred. Anwendungsbeispiele furdas vAnftragschwei – Ben nach dem Ellira – Verfahren. “SchwiBtechnik” (Oster) №10.- 2012. – P.113-115.

[8]Epaarachi, J. A. and Clausen, P. D., «An Empirical Model for FatigueBehaviour Prediction of Glass-fibre Reinforced Plastic Composites for Various StressRatios and Test Frequencies,)) Composites Part A: Applied science and manufacturing, т. 34, № 4, pp. 313-326, 2003.

[9]Guadagnini, M., Pilakoutas, K. and Waldron, P., «Shear Resistance of FRPRC Beams: An Experimental Study,» Journal of Composites for Construction, т.10, №6, pp. 464-473, 2006

[10]fib bul.40, FRP reinforcement in RC structures. Technical report TG9.3., Lausanne, Switzerland: fib, 2007.

[11]fib bul. 55, ModelCode 2010. First complete draft, Lausanne, Switzerland: fib, 2010.

[12] Brik V.B., Performance Evaluation of 3-D Basalt Fiber Reinforced Concrete & Basalt Rod Reinforced Concrete, Washington: Transportation Research Board, 1998.

[13]Brik V.B., Advanced Concept Concrete Using Basalt Fiber/BF Composite Rebar Rein-forcement, Washinton: Transportation Research Board, 2003.

[14]DSTU-N B V.2.6-185:2012 Discipling from planning and making of concrete constructions with a non-metal composite armature on the basis of basalt- and glassroving:- Kyiv.: Ukraine, 2012 -(National standard of Ukraine).

[15]Koval P. M. Work of road bridges under the influence of low cycle loads. Autotrain of Ukraine, № 3, pp. 34-37, 2006

[16]Bridges and pipes. Planning rules [Text]: DBN V.2.3-14: 2006 (state standard), Kyiv, 2011, 359 p.