TO THE CALCULATION OF BENDING REINFORCED CONCRETE ELEMENTS UNDER HIGH-LEVEL LOW-CYCLE LOADS.

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Annotation

This article presents the results of experimental and theoretical studies of bending reinforced concrete elements under low-cycle repeated-variable loads of a high level of the same sign and alternating sign. An approximate relationship is proposed for determining the deflection and crack opening width of reinforced concrete elements under low-cycle repeated loads, taking into account the load level, number and characteristics of the cycle.

At present, methods for calculating reinforced concrete structures with single and multiple repeated applications of load have been quite fully developed and included in regulatory documents. At the same time, many reinforced concrete structures are repeatedly subjected to variable (low-cycle) loads (wind, technological, seismic).

The action of such loads can cause a special type of progressive destruction in the structure, when deformations and cracks of a structure increase indefinitely with repeated - variable application of loads exceeding a single maximum load. Therefore, when calculating the strength, deformability and crack resistance of reinforced concrete bending elements for low-cycle, repeatedly variable loads, one of the main tasks is to determine the level of loading, at which stabilization of deformations still occurs, that is, after a certain number of loading cycles, the increase in deformation (displacement) stops.

This article presents the results of experimental and theoretical studies of bending reinforced concrete elements under monotonous loading with steps, repeated loading of the same sign and alternating sign repeated (low-cycle) loading, followed by bringing the samples to failure.

Scope and content of low-cycle tests of reinforced concrete beams

№	Series name	Number of samples, pcs.	Characteristics of cycles				Goal test
			Load level	Duration cycle, in minutes	Intervals minutes	Number of cycles	
1	BSht	2	Monotonous loading to failure				Determination of the load-bearing capacity of reinforced concrete beams
2	BShtC	2					
3	BShtC	2	$\dfrac{0{,}5}{0}$	30	$\dfrac{15}{15}$	10	Study of the influence of low-cycle load on the
4	BShtC	2	$\dfrac{0{,}8}{0}$	30	$\dfrac{15}{15}$	10	

5	BShtSC	2	$\dfrac{0,5}{-0,5}$	60	$\dfrac{30}{30}$	10	strength, deformability and crack resistance of reinforced concrete beams
6	BShtSC	2	$\dfrac{0,8}{-0,8}$	60	$\dfrac{30}{30}$	10	

Note: Beam brand BShtC and BShtSC mean; B- beam, Sht- short-term, C- cyclical, S - symmetrical reinforcement.

According to the experimental research program, all beams were divided into two subgroups - for short-term and low-cycle tests.

Both short-term and cyclic tests of reinforced concrete beams were carried out according to the scheme of a single-span free-lying beam with a design span of 2000 mm, loaded with thirds of the span. To test reinforced concrete beams for alternating loads, special installations were designed (Fig. 1). The main difference between the installations used and installations of a similar type is that when testing a reinforced concrete beam for an alternating periodic load, there is no need to turn the sample over and rearrange the instruments.

Analysis of experimental data shows that the impact of repeated loads of one and two signs significantly affects the compressive deformation, stretched zones of bending elements, as well as deflection and crack opening width.

The final deflection of beams increases from cycle to cycle, as do deformations $\varepsilon_\text{в}$ and ε_s 6-10% for beams series BShtC-$\dfrac{0,5}{0}$, and in beams of the BShtC series -$\dfrac{0,8}{0}$ on 25...40%.

Moreover, these deformations grow most intensively in the first 4-5 cycles. Subsequently, the growth of deformation in beams of the BShtC series slows down.

Alternating low-cycle impacts most significantly affect the deformability of beams with symmetrical reinforcement. In this case, from cycle to cycle, unilateral accumulation of deflection occurs, i.e. deflections increase with a positive moment (as with beams of the series BShtC - $\dfrac{0,5}{-0,5}$, as well as in beams of the series BShtSC -$\dfrac{0,8}{-0,8}$.

Total deflections after 10 cycles of exposure to alternating loads exceeded the deflection by 1.16 times for the beams of the series BShtSC - $\dfrac{0,5}{-0,5}$, and for beams of the series BShtSC -$\dfrac{0,8}{-0,8}$ by 1.5 times.

Increase in deflections of reinforced concrete elements under low-cycle repeated variable loading of one and two signs, occurs due to the accumulation of residual and increase in elastic deflections (especially for beams of the series BShtSC -$\dfrac{0,8}{-0,8}$), which leads to a decrease in rigidity due to a decrease in the elastic modulus of concrete and a change in the coefficient ψ_s [1,2,3,4]. A feature of the crack formation process under repeatedly variable low-cycle loads of the same sign is the development of cracks in height and width with a constant distance between them.
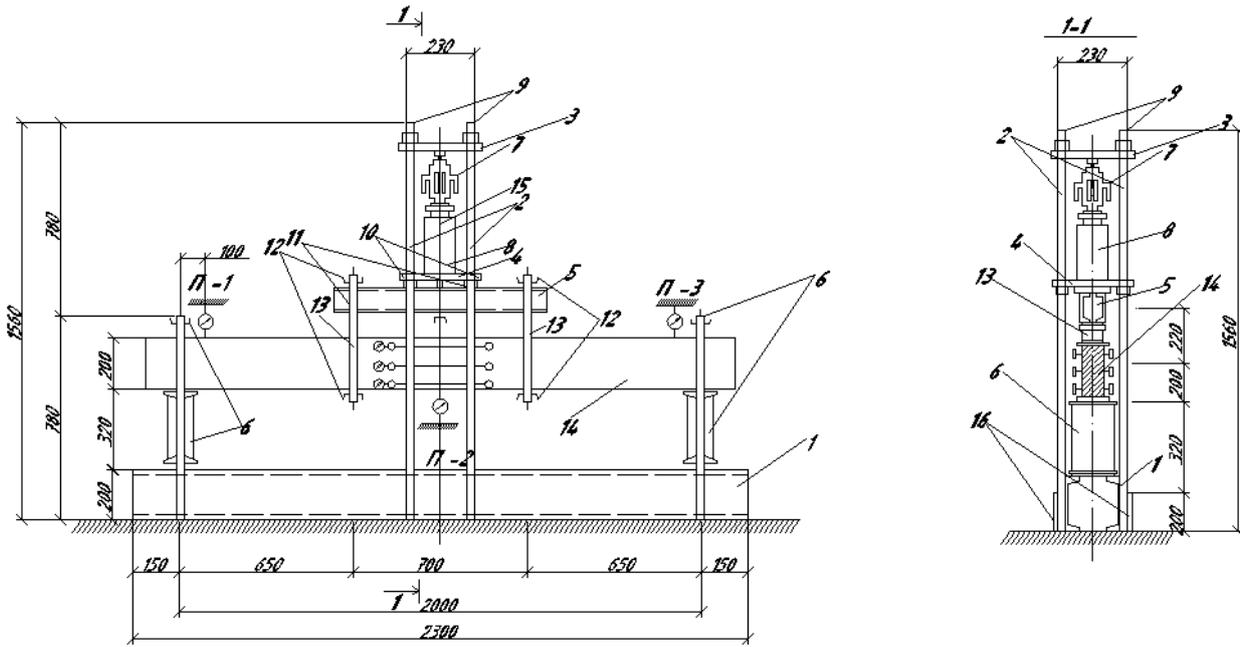
Fig.1. Design of an installation for alternating bending of beams

1-base; 2-racks; 3,4-thrust plates; 5-distribution traverse; 6-supports; 7-dynamometer; 8-hydraulic jack; 9,10-fixing nuts; 11,15-strands; 14-sample – beam

With alternating loading (series BShtSC - $\dfrac{0,5}{-0,5}$ and BShtSC - $\dfrac{0,8}{-0,8}$) an increase in the number of loading cycles leads not only to the development of cracks in width and height, but also to the formation of new cracks. This is due to a decrease in the tensile strength of concrete under alternating cyclic loading (low-cycle fatigue). Complete removal of the load leads to only partial closure of cracks with a residual width of no more than 0.025-0.05 mm.

Under repeated low-cycle constant-sign loads, the crack width increased by 15...20%, for beams of the series BShtSC - $\dfrac{0,5}{-0,5}$, and for beams of the series BShtSC - $\dfrac{0,8}{-0,8}$ on 1,5 times.

Under alternating loads of beams of the series БКсЦ - $\dfrac{0,5}{-0,5}$ on 1,25 times and series BShtSC - $\dfrac{0,8}{-0,8}$ on 60...65%.

Apparently, neglect of this circumstance by modern design standards leads to the fact that there is a significant discrepancy between the experimental and calculated values of deflections and crack opening widths of reinforced concrete elements.

It is proposed to take into account the influence of low-cycle repeated-variable loads on deflection and crack width in the following way:

$$\overline{f} = f_O \cdot K(\eta, \rho, n) \qquad (1)$$

where; $\overline{f}$ - element deflection under repeatedly variable low-cycle loads.

f_O - initial deflection

$K(\eta, \rho, n)$ - coefficient taking into account the level, number and characteristics of periodic load cycles

n - the number of cycles

ρ - cycle characteristics $\rho = \dfrac{M_{\min}}{M_{\max}}$;

η - load level $\eta = \dfrac{M_{исп}}{M_{раз}}$;

$$K(\eta, \rho, n) = (0,5 + \eta) \cdot \left(1 + \sum_{i=1}^{n} \left(a\sqrt{1+\rho}\right)\right)^{i} \tag{2}$$

a – experienced parameter. Based on the data of experimental studies and studies of other authors, we selected; $a = 0,098$

To determine the increase in crack opening width, it is recommended to use a relationship similar to (1)

$$\bar{a}_{crc} = a_{crco} \cdot K(\eta, \rho, n) \tag{3}$$

$$K(\eta, \rho, n) = (0,5 + \eta) \cdot \left(1 + \sum_{i=1}^{n} \left(в\sqrt{1+\rho}\right)\right)^{i} \tag{4}$$

$i = 1,2,3..., n; \quad в = 0,142$

The average deviation of the calculated values from the experimental ones when using relations (2) and (4) is no more than ±5%. Based on the processing of the results obtained, it was established that constant-sign and alternating-sign static repeated loads with an intensity of (0.5...0.8) M times with constant amplitudes and with a number of cycles n≤10 noticeably affect only the deformability and crack opening width, but practically do not reduce their bearing capacity. As can be seen from the article, the authors are supporters of approximate calculation methods. Naturally, in cases where there is the slightest possibility of using a more mathematically rigorous theory, it is necessary to give it preference. Meanwhile, engineering practice cannot wait for the full development of analytical theory or the accumulation of statistically reliable constants; it requires the calculation of structures and structures in difficult operating conditions, although approximately, perhaps estimated, but today and not in the distant future.

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