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INVESTIGATION OF THE BEHAVIOR OF SUPPORT ZONES OF CONTINUOUS REINFORCED CONCRETE BEAMS UNDER REPEATED AND LOW-CYCLE ALTERNATING LOADS

ДОСЛІДЖЕННЯ РОБОТИ ПРИОПОРНИХ ДІЛЯНОК НЕРОЗРІЗНИХ ЗАЛІЗОБЕТОННИХ БАЛОК ЗА ДІЇ ПОВТОРНИХ І МАЛОЦИКЛОВИХ ЗНАКОЗМІННИХ НАВАНТАЖЕНЬ.

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Based on the authors' and other researchers' experimental studies, this article presents an analysis of the behavior of inclined sections in the support zones of single-span and continuous reinforced concrete beams under low-cycle loads and changes in the stress-strain state depending on the shear span of the external load application.
The calculation of reinforced concrete beams inclined crack is due to many interdependent factors. Beam testing attempts to identify the main criterion for the strength of the inclined section and, based on this, proposes a method for calculating inclined sections.
The accuracy of calculating the strength of inclined sections of reinforced concrete beams on the action of the transverse force and bending moment according to the methods, according to methods based on the theory of concrete strength fully depends on the reliability of the assumptions made and functional expression of tangent stresses and normal stresses taking into account factors, considering the factors that characterize the behavior of the reinforced concrete element in the shear span.

If we compare these calculation methods with the method based on the equilibrium of limiting forces, the latter is the least labor-intensive for designers.
Current regulatory documents [1] propose a method for calculating inclined sections using a strut-and-tie model (truss analogy of the new European standards [2]), which also has a number of difficulties in actual calculations of the transverse sections of beams. In this case, bent bars in beams can be used as transverse reinforcement in combination with vertical transverse bars.

За результатами експериментальних досліджень авторів і інших дослідників в статті наведено аналіз роботи похилих перерізів приопорних ділянок одно пролітних і нерозрізних залізобетонних балок за дії малоциклових навантажень і зміни напружено-деформованого стану в залежності від плеча зрізу прикладання зовнішнього навантаження.
Розрахунок залізобетонних балок по похилій тріщині обумовлений багатьма взаємно залежними факторами. При випробуванні балок намагаються виявити основний критерій міцності похилого перерізу і на цій основі пропонують методику розрахунку похилих перерізів.
Точність розрахунку міцності похилого перерізу залізобетонних балок на дію поперечної сили і згинального моменту за методиками, в основі яких лежить теорія міцності бетону, цілком залежить від достовірності прийнятих припущень, функціонального виразу дотичних і нормальних напружень з урахуванням факторів, які характеризують роботу залізобетонного елемента в прольоті зрізу.
Якщо порівняти ці методики розрахунку з методикою, яка заснована на рівновазі граничних зусиль, то остання для проектувальників є найменш трудомісткою.
В діючих нормативних документах [1] запропонована методика розрахунку похилих перерізів за моделлю стержневої системи (фермової аналогії нових європейських норм [2]), яка також має ряд труднощів при реальних розрахунках поперечних перерізів балок. В даному випадку відігнуті стержні в балках можуть бути використані як поперечне армування в поєднанні з поперечними вертикальними стержнями.

Keywords: inclined sections, support zones, reinforced concrete beams, low-cycle alternating loads.

Introduction. A significant number of reinforced concrete beams, both single-span and so indistinguishable, used in construction are subjected to long-term effects of repeated and alternating low-cycle loads during operation.

The job of materials in beams under low-cycle alternating loads and their resistance differs significantly from their behavior under constant static loads, in particular, failure can occur at stress levels well below than the ultimate strength.

For today known that the resistance of reinforced concrete elements with the combined action of bending moments and transverse forces is one of the most important and not fully resolved problems, both in the theory of reinforced concrete and in the actual design of efficient reinforced concrete structures. While many publications address the strength calculation of normal sections of reinforced concrete elements in both domestic and international literature, the strength calculation of inclined sections especially in continuous reinforced concrete structures has received far less attention and remains far from perfect.

Analysis of Recent Studies. As mentioned above, the study of inclined sections in bending reinforced concrete elements has been addressed in only a limited number of works. These are the works of such scientists as Barashikov A.Ya. [3,4], Dmytrenko A.O. [5], Dorofeev V.S. [6,7], Doroshkevych L.O. [8,9], Klimov Yu.A. [10], and Mitrofanov V.H. [11,12].

As for the study of reinforced concrete elements under low-cycle repeated loads, the most notable works are by Babich E.M. and his students [13,14]. All the present study was conducted on single-span elements under static loading.

Large-scale experimental studies of reinforced concrete elements under the action of alternating loads were carried out by Prof. Makarenko L.P. and his students [15,16]. These studies were also carried out on statically determined elements.

The results of studies uncut reinforced concrete flexural elements are presented in the works of Babich V.E. [17] and Dorofeev V.S. [18].

In recent decades, research has developed a new approach to the calculation of reinforced concrete elements and structures, which are characterized by complex structural forms,stress-strain state and loading conditions, based on finite differences, finite and boundary elements. This approach is based on finite difference, finite element, and boundary element methods. Significant contributions in this field have been made by Babich E.M. [19], Bambura A.M. [20,21], Davydenko A.I. [22], Mitrofanov V.P. [23], and Yaremenko O.F. [24].

Purpose and Research Objectives. The aim of this article is to show the development of scientific foundations for studying the operation of bearing sections of continuous reinforced concrete beams subjected to low-cycle alternating loads and to analyze the methodology for calculating the strength of inclined sections based on a modern deformation model of sections. Also, to verify the current methods for determining crack resistance and deformability based on experimental data.

Main Text. To achieve the set goals and objectives, experimental testing of continuous reinforced concrete beams under various modes and load levels was conducted in the laboratory of the Department of Industrial, Civil Construction and Engineering Structures. All beams were two-span, 300 cm long, with a cross-sectional dimension of 10×16 cm, made from C25/30 concrete. Beams were reinforced with welded frames. The working longitudinal reinforcement consisted of two 12 mm diameter bars made of A-400 steel, and the transverse reinforcement consisted of 6 mm diameter bars made of B-500 steel with a spacing of 100 mm in support zones and 200 mm in in the middle spans of the beams. In beams tested under low-cycle alternating loads, the working longitudinal reinforcement was placed both at the top and bottom within the frames.

To determine the physical and mechanical properties of the concrete, cubes with edge sizes of 10 and 15 cm and prisms of 15×15×60 cm were made, as well as 10×10×60 cm prisms for determining tensile strength.

To better understand the physical process of beam failure, the average physical and mechanical characteristics of the longitudinal reinforcement were obtained by testing samples in tension according to GOST 1204-81.

Deformations in the concrete and reinforcement of the beams in the corresponding sections were measured using modern strain-gauge devices.

Beams labeled BOS-1 (three samples) were tested under one-time short-term static loading up to failure.

Beams labeled BMCP-1 (three samples)were tested by repeated short-term loading, the level of which was 60% of the ultimate load [$\eta = F_{eye} / F_u$], where Fu is the ultimate load determined from the BOS beam tests. These BMCP beams were subjected to ten load cycles up to $\eta = 0.6$, then unloaded to $\eta = 0.3$, and so on for ten cycles, after which they were loaded to failure.

Beams labeled BMCZN-1 (three samples) were subjected to low-cycle repeated alternating short-term loading up to $\eta = 0.6$, then unloaded to zero and reloaded to the same level with the opposite sign. After ten cycles, the beams were loaded to failure.

The choice of the basic amount of repeated and alternating load is due to the fact that, that according to the data to many researchers, deformation processes in concrete at the accepted load levels for continuous beams are stabilized within 5 or 10 cycles.

The results of experimental tests on continuous reinforced concrete beams under the above-mentioned loads showed the following. The work and the stress-strain state of such beams, including the support sections, under the action of low-cycle repetitive and sign-changing loads differ significantly from the stress-strain state of beams tested by static single-value short-term loads. The change in the bearing capacity of the tested beams is given in Table 1. The failure of all types of beams was of the same type and occurred along inclined sections near the middle supports, where the largest transverse forces and bending moments act.

As for the deformability and crack resistance of the tested beams, it should also be noted that these parameters also differ depending on the nature of the loads. Under the action of low-cycle repeated loads at the level η=0.6 after ten cycles, the deflection values increased by 15%, and under the action of low-cycle alternating loads at the level η=0.6 - by (35-40)% compared to the values in the BOS beams. As for crack widths, under low-cycle repeated loads at $\eta = 0.6$, after ten cycles, normal cracks increased by 20%, and inclined ones near the middle support by 40%. Under the action of low-cycle alternating loads at the level of ƞ=0.6 after 10 cycles, the width of crack opening increased by 25% and 45%, respectively. It should also be noted that the patterns of crack formation and opening under the action of low-cycle repeated and alternating loads are significantly different from the patterns of crack formation and opening under a single static load, which significantly affects the operational characteristics of continuous beams. When working with beams are operated under low-cycle repeated loading, crack development progresses up to 4-5 cycles, and then stabilization of the width of crack opening and closing is observed.

Table 1.

Average Load Values of the Beams

Code of beams	The force at which the beams collapsed F, [kH]	Bending moments during destruction		Modes of loading
		In the span M, [kHm]	On the middle support M, [kHm]	
BOS	32.5	10.4	14.4	One-time static load to failure
BMCP	30.0	9.64	13.3	Short-term low-cycle repeated, after 10 cycles to failure
BMCZN	27.5	8.84	12.2	Short-term low-cycle alternating, after 10 cycles to failure

When working with inseparable beams under the action of low-cycle alternating loads, a significant development of the width of normal cracks is observed in the first two cycles, and after the third to fifth cycles, the normal cracks practically divided the beam cross-section into separate blocks upon arrival, i.e. merged from the stretched to the compressed cross-section zone with their subsequent opening in the following cycles. As for the inclined cracks on the supporting sections, they were formed in the fifth cycle. After the tenth cycle, when the load increased to the level of =0.8 of the destructive one, a critical inclined crack with a width of W=0.5 mm was formed, along which the beams of BMCZN collapsed.

These studies were conducted for beams with a shear span near the central support of a = 600 mm. According to the works of Kh. Hasan [25] and V.P. Mitrofanov [26], the strength and crack resistance of inclined sections depend on the shear span. Therefore, further experimental studies are planned on the behavior of support zones in continuous reinforced concrete beams under low-cycle alternating loads with different shear spans.

Conclusions. Based on the analysis of the conducted experimental studies of the operation of uncut reinforced concrete beams under the action of low-cycle repeated and sign-changing loads, it is recommended to consider when designing such structures for use in real construction. Based on the conducted research, check and improve the current method of calculating inclined sections.

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