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THE EXPERIMENTAL RESEARCHES OF REINFORCED CONCRETE I-BEAM ELEMENTS WITH NORMAL CRACKS WHEN TURNING

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The data of experimental researches of the rigidity of reinforced concrete I-beam elements with normal cracks at the action on them of the twisting moment have resulted in this paper. It is shown that the dependence "torque-twist angle" is almost linear. Significant nonlinear deformations appear in the last stages of loading before failure. Therefore at normative torques, it is recommended to consider the work of reinforced concrete elements of the I-beam cross-section with normal cracks linear. It is shown that the presence of longitudinal reinforcement affects the strength and rigidity of beams with normal cracks. Quite a large part of the external torque is perceived by the pin forces in the longitudinal reinforcement. The difference between the external torque and the moment of the pin forces in the armature is perceived by the upper shelf of the I-beam element. In the absence of longitudinal reinforcement, the upper shelf can collapse at loads much smaller than the destructive load of beams with longitudinal reinforcement.

Keywords: I-beam, torsion, normal cracks, torsional strength, longitudinal reinforcement, pin force

ЕКСПЕРИМЕНТАЛЬНІДОСЛІДЖЕННЯЗАЛІЗОБЕТОННИХ ДВОТАВРОВИХ ЕЛЕМЕНТІВ З НОРМАЛЬНИМИ ТРІЩИНАМИ ПРИ КРУЧЕННІ

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Встановлено і представлено залежність «крутний момент-кут закручування»,вона є практично лінійною. Суттєві нелінійні деформації з'являються на останніх етапах навантаження перед руйнуванням. Тому при нормативних крутних моментах рекомендовано вважати роботу залізобетонних елементів двотаврового поперечного перерізу з нормальними тріщинами лінійною. Показано, що наявність поздовжньої арматури впливає на міцність і жорсткість балок з нормальними тріщинами. Достатньо велику частину зовнішнього крутного моменту сприймають нагельні сили в поздовжній арматурі. Різницю між зовнішнім крутним моментом і моментом нагельних сил в арматурі сприймає верхня полка двотаврового елементу. При відсутності поздовжньої арматури верхня полка може руйнуватись при навантаженнях, набагато менших, ніж руйнуюче навантаження балок з поздовжньою арматурою. Армування експериментальних балок з нормальними тріщинами тільки поздовжньою арматурою суттєво впливає на їх жорсткість. На міцність при крученні поздовжня арматура елементів з нормальними тріщинами впливає не так суттєво, як на жорсткість. Достатньо велику частину зовнішнього крутного моменту сприймають нагельні сили в поздовжній арматурі. Різницю між зовнішнім крутним моментом і моментом нагельних сил в арматурі сприймає верхня полка двотаврового елементу. Збільшення діаметра поздовжньої арматури призводить до зменшення деформацій і відповідно збільшення жорсткості балок при крученні. На основі експериментальних досліджень і враховуючи попередні теоретичні дослідження автора спростовано здавна існуючу думку про те, що поздовжня арматура не впливає на міцність при крученні. Наведені факти, на погляд автора, повинні бути враховані при проведенні практичних розрахунків несучих систем залізобетонних будівель і споруд.

Ключові слова: двотавровий елемент, кручення, нормальні тріщини, жорсткість і міцність при крученні, поздовжня арматура, нагельна сила

Introduction

It is known that considering the spatial work of repeatedly statically indeterminate systems (concrete floors, bridges, frameworks of buildings) can significantly clarify the efforts arising in the individual elements of a complex system. It is also known that the redistribution of forces among the individual elements of statically indeterminate systems depends on the ratio of bending and torsional stiffness of these elements [1]. At the same time, in reinforced concrete statically indeterminate systems, the formation of various cracks (normal, inclined, spatial, separation cracks, etc.) influences the bending and torsional rigidity. Normal cracks are formed at low enough load levels. The formation of cracks entails an abrupt change in the stiffness of the element, and the stiffness can be reduced several times.

Review of research sources and publications

With a fairly broad exploration of reinforced concrete elements stiffness in bending, their stiffness and torsional strength are studied insufficiently. The main attention in scientific works and normative documents devoted to the work of reinforced concrete elements during torsion is paid to elements with spatial (spiral) cracks [4, 5, 9, 11, 12].

However, experimental and theoretical studies have shown [1, 3, 10] that normal cracks also significantly affect the torsional rigidity of the reinforced concrete elements. Numerous and approximate methods for determining the torsional stiffness of elements of rectangular, T-shaped, box-shaped, and hollow triangular sections are considered in [1, 3, 6 - 8]. In [2] the issues of reinforced concrete I-beams stiffness and torsional strength calculation are considered. Publications [6 - 8] are devoted to the experimental study of the reinforced concrete elements work of the rectangular, box, and hollow triangular cross-section.

However, stiffness and strength experimental studies of reinforced concrete I-beams with normal torsional cracks were not performed.

Objective of the work and research methods

Due to the above-mentioned content, the aim of this article is an experimental study of the strength and rigidity of reinforced concrete I-beams with normal cracks under the influence of turning.

Basic material and results

In the course of the experiment, it was supposed to investigate the torsional rigidity and strength of reinforced concrete elements of the I-beam section with normal cracks on the models. There were made samples with data presented in Fig 1.

The aim of the research was to establish the nature of changes in the stiffness characteristics of samples with different diameters of longitudinal reinforcement and different cross-sectional dimensions. Due to the fact that the author theoretically found out that for I-beams with a small wall thickness, the crack height does not play a significant role, it was decided to take the same normal crack height equal to half the cross-sectional height, and vary the cross-sectional size and reinforcement diameter.

Artificial normal cracks were created using Perspex plates, which were inserted at the location of the crack when laying concrete in the formwork. Such cracks divided the samples along the length into separate blocks, interconnected by a part of concrete without cracks and longitudinal reinforcement (Fig. 2). The length of the blocks was 300 mm. In addition, three samples were made solid, without artificial normal cracks.

To analyze the experimental data and establish the relationship between the parameters of deformation (twisting angle of the blocks separated by cracks) and the magnitude of the external load were plotted "torque-twisting angle". The sketches 3-5 present such graphs for some tested beams as samples.

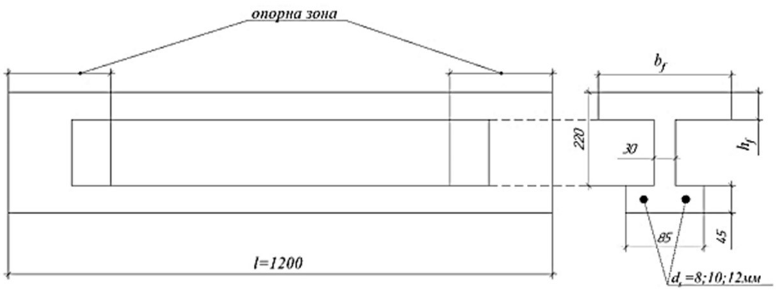

Figure 1 – Dimensions of experimental samples

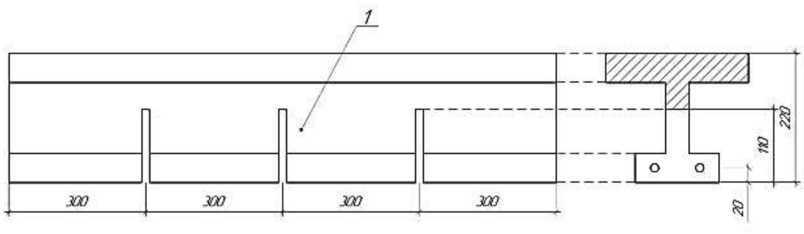

Figure 2 – Scheme of the formation of artificial cracks and reinforcement of samples (1 – Perspex)

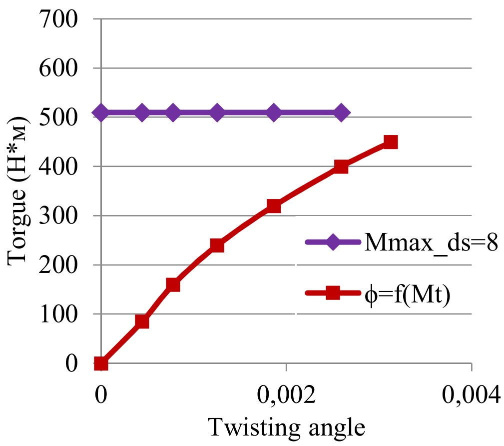

Figure 3 – Twisting angles and destructive moments for beams with dimensions: b_f = 300 mm; h_f = 30 mm; d_s = 8 mm

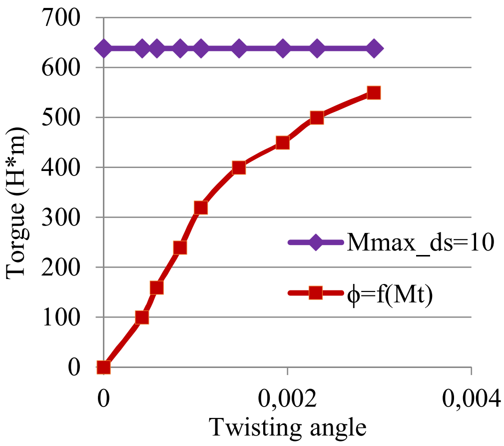

Figure 4 – Twisting angles and destructive moments for beams with dimensions: b_f = 300 mm; h_f = 40 mm; d_s = 10 mm

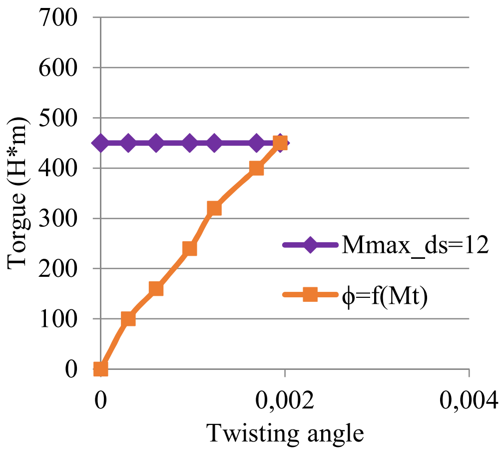

Figure 5 – Twisting angles and destructive moments for beams with dimensions: b_f = 300 mm; h_f = 40 mm; d_s = 12 mm

Also besides the dependencies of the "torque-twisting angle" the maximum torque values Mmax is shown, i.e. the destructive torque, in addition to the torque-to-twist dependencies. In the penultimate stages of the load measuring instruments were removed to prevent their destruction, thus there are no dimensions of the twist angles during failure.

In the figure it can be seen that the "torque-twist angle" dependence is almost linear. Significant non-linear deformations appeared in the last stages of loading before failure. Therefore at normative loadings it is possible to consider work of samples linear.

Beam with dimensions b_f = 300 mm; h_f = 40 mm; d_s = 12 mm (see Fig. 5) was prematurely slightly destroyed by puncturing the longitudinal reinforcement, which is most likely a disadvantage of its concreting. Therefore, its destructive moment is much smaller than the destructive moments of other beams of the same series.

The pattern of cracking of all samples with artificial normal cracks was similar. An inclined crack appeared from the top of the artificial crack and extended to the beam top shelf. In the future, the picture of several stages of the load remained unchanged. In some samples, the concrete peeled off near the longitudinal reinforcement, but it did not affect the strength of the samples, except for the sample (see Fig. 5). Upon further loading, a spatial crack appeared in the beam upper shelf. The deformations increased significantly. Then the moment of beam destruction came.

In fig. 6 a general view of an inclined crack starting at the top of an artificial normal crack is shown.

Analyzing the experimental data, it can be stated that the presence of longitudinal reinforcement affects the strength and rigidity of the beams with normal cracks. [16 – 20]. Quite a large part of the external torque is perceived by the pin forces in the longitudinal reinforcement. The difference between the external torque and the moment of the nail forces in the reinforcement is perceived by the upper shelf of the I-beam element. In the absence of longitudinal reinforcement, the upper shelf can collapse at loads much smaller than the destructive load of beams with longitudinal reinforcement. This fact is confirmed by the premature destruction of the beam, which is described above, from the puncture of the longitudinal reinforcement [13 – 14].

Unlike beams with artificial normal cracks, sloping cracks at the edge initially appeared in the beams without cracks (Fig. 11). These cracks then spread to the lower and upper shelves. A space crack appeared on the top shelf. At the same time deformations sharply increased. After that, the beams collapsed as a result of a loss of the upper shelf load-bearing capacity. Destructive moments of beams without cracks were slightly larger than moments of beams with cracks [15].

In pictures 9-10 there are shown graphs of "load-twist angle" for the beams without artificial normal cracks.

Figure 6 – Inclined crack from the top of the artificial normal crack in the beam

Figure 7 – The destruction of the beam

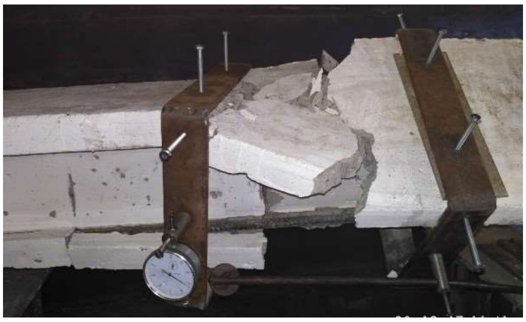

Figure 8 – Premature destruction of the beam as a result of puncturing the longitudinal reinforcement

For comparison with experimental data in Fig. 9-10 graphs of the elastic calculation of these beams in the program вЂњLiraвЂќ using three-dimensional finite elements are shown. The figures confirm the elastic nature of work to high levels of load.

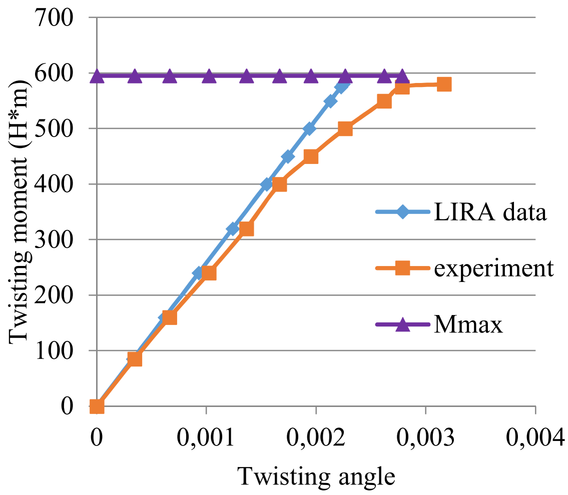

Figure 9 – Twisting angles and destroying moments for the beam without cracks (d_s=8 mm)

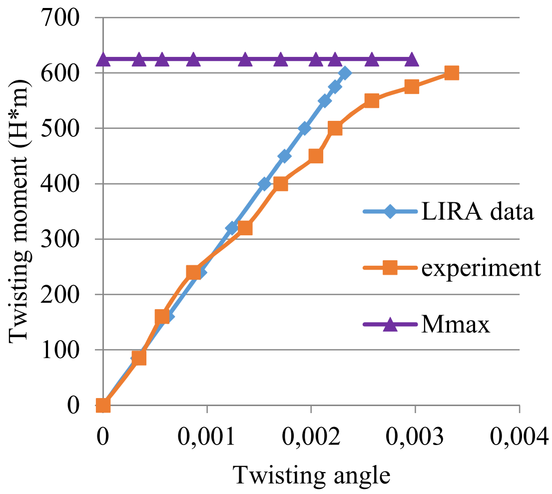

Figure 10 – Twisting angles and destroying moments for the beam without cracks (d_s=10 mm)

Figure 11 – General view of of an inclined crack at the edge

Conclusions and the prospects of research

Experimental studies have shown that the "torque – twist angle" diagram of reinforced concrete elements of the I-beam section with normal cracks to high load levels is linear. Plastic flows take place in the last stages of loading, before destruction. The main type of failure is the destruction of the I-beam element upper shelf with the development of a spatial torsional crack.

The experimental beams reinforcement with normal cracks only by longitudinal reinforcement significantly affects their rigidity. The longitudinal reinforcement torsional strength of elements with normal cracks does not affect as significantly as the stiffness. Quite a large part of the external torque is perceived by the nail forces in the longitudinal reinforcement. The difference between the external torque and the moment of the nail forces in the reinforcement is perceived by the upper shelf of the I-beam element.

Increasing the longitudinal reinforcement diameter leads to decrease in deformation and, accordingly, to increase in the beams stiffness during torsion. Increasing the stiffness and strength of the top shelf affects both the beams overall stiffness their strength.

The research shows that the torsional strength of reinforced concrete elements depends on the cross-section of the longitudinal reinforcement in the presence of normal cracks, which refutes the long- held supposal that the longitudinal reinforcement does not affect the torsional strength. These facts, in the opinion of the author, should be considered when conducting practical calculations of reinforced concrete buildings and structures load-bearing systems.

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