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Experimental investigation of reinforced concrete beams using post- tension

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Abstract. The paper presents the results of an experimental investigation of statically determinable pre-stressed concrete beams with tension on concrete (using post-tension). The authors consider the existing practice of applying post-tension in reinforced concrete structures, the current regulatory documents of the Russian Federation containing information on the strength and deformation properties of post-tension. The paper contains information about the loading pattern, beam-fixing conditions, geometric characteristics of a reinforced concrete beam, physical characteristics of concrete and reinforcement of an experimental sample, technical characteristics of pre-stressed reinforcement. The authors present the research results using graphs of structural deflection changes under load, the distribution of relative strain along the depth of a concrete cross-section, as well as cracking and failure schemes of experimental samples. The research presented in the paper showed that the destruction of the samples occurred along a standard cross-section and was brittle. As a result of processing the results of experimental data, loads of crack formation and critical crack width were determined. The authors confirmed the effect of pre-stressing on crack resistance and the magnitude of the deflection of bent reinforced concrete elements.

1. Introduction

The use of pre-stressed reinforced concrete structures with post-tension can significantly reduce the consumption of material during construction and last but not least to increase the permissible spans of structures and reduce the magnitude of the deflection in the ultimate state[9-12].

Pre-stressed structures can be divided into two types according to the applying tension method – pre-stressed structures with reinforcement tension to concrete strength and pre-stressed structures in which special reinforcement is tensioned on concrete after the concrete has gained considerable strength.

In the USA and European countries, the post-tension method has become widespread [1-2]. With its use, many buildings and structures have been erected for various purposes. In domestic construction, it is much less common, mainly the construction of bridges and overpasses. Largely, this is due to the almost complete absence of recommendations for the calculation of such structures in the domestic regulatory literature. The only references to post-tension structures are limited by production technology, general recommendations for use in long-span structures. Regulatory Guidelines for calculation are contained in [3-5, 7], however, there is little information concerning post-tension. In foreign Standards [1, 2], there are much more design recommendations and their application is allowed when calculating a much larger list of structures. Despite the weak support of the regulatory framework for the design of post-tensioned structures, this type of building structures is used in modern domestic construction. The ability to withstand the load in the structure without adhesion to concrete using the location of pre-stressed cables in reinforced concrete cross-section provides high flexibility in the shape of structures. The technology allows designing durable structures with a minimum of required maintenance. The structural solution of post-tension beams is quite complicated and requires considering many factors and quantities at the design stage. Post-tensioned structures are very demanding of the quality of building materials and the technological process. However, at the same time, they allow significantly saving on the cost of materials during construction and making it possible to optimize planning decisions, significantly increase the span of structures, reducing the size of the section without losing bearing capacity and reduce the total weight of the structure.

2. Materials and Methods

The aim of this work, following the carried out investigation [14-16], is to study the operation of single-span post-tension reinforced concrete beams strained by K15 steel ropes [8] laid along a parabolic curve and to compare them to the operation of similar beams reinforced without stressed reinforcement.

Research Objectives:

1. To determine the breaking load for experimental samples;
2. To study the stress-strain state of structures;
3. To fix the formation, development and cracks width, the magnitude of the beam deflection.
4. To compare and analyze the results obtained during the test.

We used reinforced concrete beams as samples manufactured at the factory with the following characteristics: beam cross-section - 200x400 (h) mm, B25 concrete type, A500C reinforcement type - [6], beam length - 3.9 m.

Reinforcement of the sample (Figure 1) consists of:

– longitudinal reinforcement along the upper edge 2 Ø12 A500C with a protective layer of 40 mm;
– longitudinal reinforcement along the lower edge 2 Ø12 A500C with a protective layer of 50 mm;
– longitudinal reinforcement along the lower edge 1 Ø16 A500C with a protective layer of 50 mm;
– lateral reinforcement Ø 8 A240 in increments of 100mm.

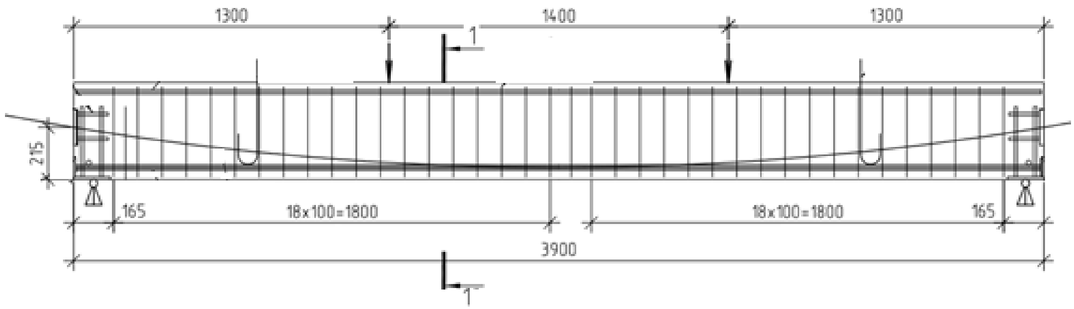

Figure 1. Prototype design

The non-tensioning reinforcement was anchored with plates 150x200x10mm welded to the ends. Metal plates 80x200x10mm were provided on the supporting sections. The steel of plates is C245. The rope is located in the sample by the non-channel method in polymer isolation.

At the test site, after processing the concrete surface in the middle of the span, resistive strain gauges with a base of 50 mm were glued on the side and upper faces of the sample. In the middle of the span, the Aistov 6-PAO 0.01-deflection meter was installed.

Preproduction tests were carried out according to the design scheme presented in Figure 2, like a hinged single-span beam loaded with two concentrated vertical forces, applied to the upper edge of the beam at a distance of 1300 mm from the ends of the sample. The tests were carried out on the power floor, in the laboratory of the Building Structures Department of ASA SamGTU. The load was applied using DG-25 hydraulic jacks connected to an in-line circuit.

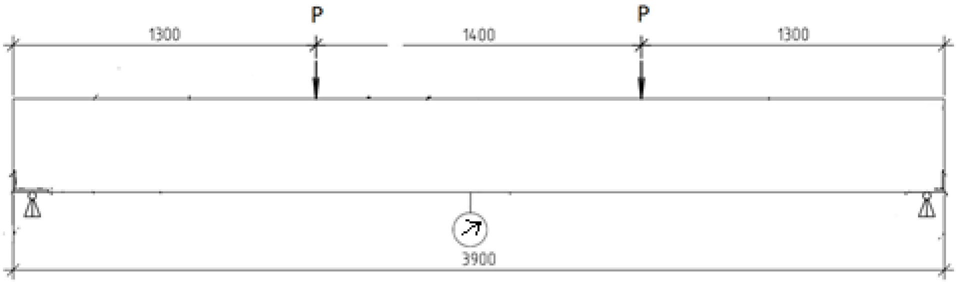

Figure 2. Design scheme of the test sample

The loading was carried out in steps of 10 MPa, which corresponds to a load of 16.4 kN. At each loading stage, the sample was held under load. At the beginning and end of the exposure, the readings of the deflection meter and strain gauges were taken. A picture of crack formation and their development was recorded and noted on the sample. The crack width was fixed separately. After testing, the samples were photographed before and after unloading.

A pilot unit for the test sample is presented in Figure 3.

a) b)

Figure 3. Pilot unit for the test sample: a) post-tension application; b) the sample before testing

3. Results and discussions

Before testing, the rope reinforcement of B1 sample had a 0.8 tension from the design resistance of this reinforcement grade. It amounted to about 96 kN. In this case, the unloaded sample received a deflection according to the readings of the deflection meter equal to 0.6 mm, which was subsequently considered a zero value when taking readings of the deflection meter.

The sample was loaded in steps of 16.4 kN and kept under load at each stage for about 15 minutes. The formation of normal cracks was recorded at the fourth stage of loading at a load of $P = 0.45P_{failure} = 67$kN. Their crack width was 0.05mm. The deflection value was 3.19 mm. At the nest stage there was $P = 0.56P_{failure} = 84$ kN, the crack width was 0.1 mm. The deflection value was 6.24 mm. The crack formation was stopped at the loading stage No. 7 at a load of $P = 0.78P_{failure} = 116$ kN with the crack width of 0.25 mm due to a significant increase in the deflection and the crack width with further loading. The deflection was 13.59 mm. The failure occurred at the ninth stage of loading at a load $P = P_{failure} = 148$kN. The failure occurred along the standard cross-section between the applied forces with a significant displacement to one of them, with the failure of the compressed concrete zone, and therefore it was brittle. The failure occurred at the stage of the sample exposure, the deflection during the exposure increased from 45.79mm to 45.19mm.

A general picture of the cracks formation and development during the test is presented in Figure 4. A general view of the sample under load after failure is shown in Figure 5.

a) b)

Figure 4. General picture of the cracks formation and development during the test: a) a general view of crack formation in the normal zone; b) the compressed concrete zone starts to peel

Figure 5. View of the sample under load after failure

Based on the results obtained when testing the beam in order to study the stress-strain state we constructed the following graphs: the load deflection graph (Figure 6), the distribution graph of deformations in concrete in the middle of the span along the section height for loads corresponding to the formation of normal cracks (the crack width is 0.05 mm) and their opening size equal to 0.25mm (Figures 7, 8).

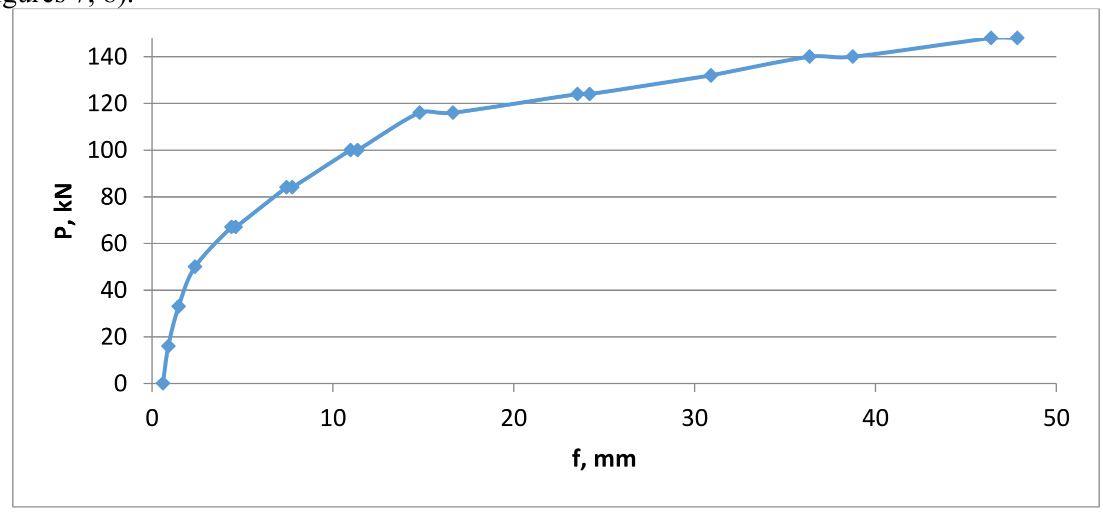

Figure 6. Prototype deflection graph

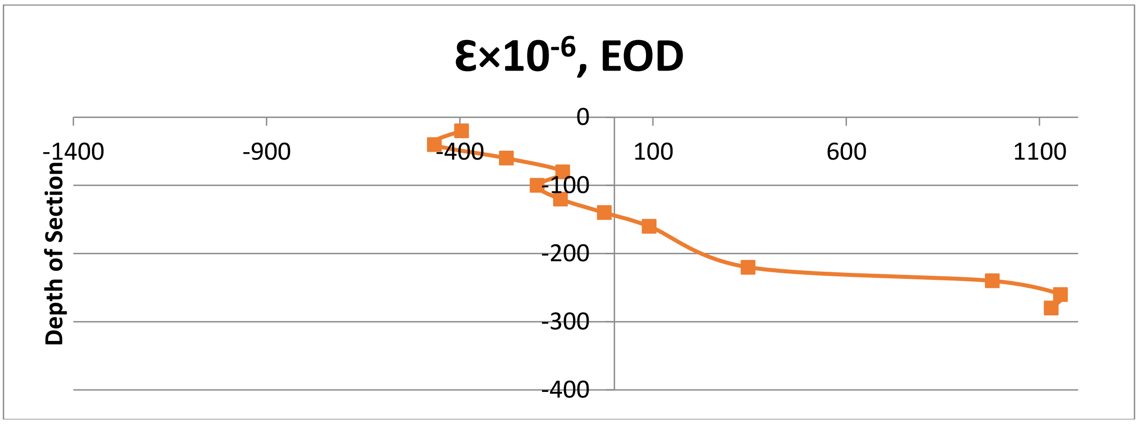

Figure 7. Strain distribution along the depth of concrete section at the load of 67 kN

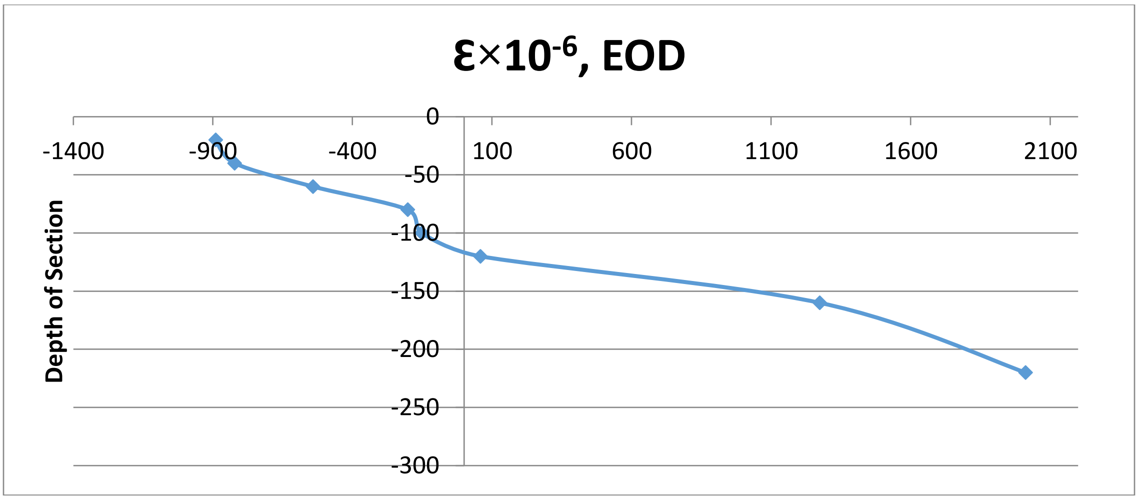

Figure 8. Strain distribution along the depth of concrete section at the load of 116kN

4. Conclusions

The experimental investigation of the post-tension feasibility was carried out in the laboratory conditions using two experimental samples, which were reinforced concrete beams with and without post-tension. The post-tension in the reinforced concrete beam was represented by rope reinforcement in the form of one K7 Ø15mm rope. The rope pre-stress size is 0.8 × Rs = 936.0 MPa. The location of the rope in the plane of the sample is parabolic, with a downward bend, to balance the effect on the sample of the load applied during the experiment. A sample without a pre-stressing element in the lower face is reinforced with a Ø16mm A500C rod. Apart from that, the reinforcement of the samples is the same.

During the experiment, it was revealed that the samples, with actually equal bearing capacity, have significantly different crack resistance. The deflections of the samples at the loading stage, until the longitudinal reinforcement reaches yield, also differ.

In a post-tensioned sample, before the formation of normal cracks, the deflection is 1.18 mm at the load of 50 kN. Normal cracks are formed at the load of 67kN. Inclined cracks are not formed. Normal cracks reach a critical opening width of 0.3 mm at the load of 116 kN. Under the critical crack width, the deflection is 13.6 mm. At the final failure of the sample, normal cracks are evenly distributed along the span. At the time of failure, the deflection was 45 mm.

In a non-stressed sample, before the formation of normal cracks, the deflection was 1.74 mm at the load of 24 kN. Normal cracking begins under the load of 33kN. Inclined cracks are formed at the load of 108 kN. Normal cracks reach a critical crack width of 0.3 mm with a load of 67 kN and the deflection of 6.69 mm. At the final failure of the sample, normal cracks are concentrated in the zone of pure bending, between the applied forces. The deflection at the time of failure was 7 cm.

Based on the results of the relative strain analysis, it was found that before the formation of normal cracks, the deformation of concrete in the post-tension sample is significantly less. After cracking, the deformations of the concrete are approximately the same.

As a result of the investigation, the following conclusions can be drawn:

1. A post-tension element with a parabolic tensile element bends more evenly, and normal cracks are formed not only in the zone of pure bending.
2. A sample without post-tension shows a classic picture of crack formation with normal cracks between the applied forces and inclined cracks between the applied forces and the support.
3. The use of tensile reinforcement in the form of a parabola allows reducing the load on the inclined section and achieving a uniform bending of the sample with the distribution of normal cracks along the span.
4. Due to the uniform bending of the post-tensioned sample, concrete deformations in the pure bending zone below develop more uniformly until the critical crack width occurs.

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