Experimental Investigation Dowel Action of Longitudinal Reinforcement of Reinforced Concrete Beams

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Abstract. The technique and results of experimental investigation on test samples of shear force magnitude (dowel action) in longitudinal tensile reinforcement in the zone of transverse bending of reinforced concrete beams after the formation of inclined cracks are presented in the article. The design of test samples, the technique of measurement of deformations at carrying out tests is described. Deformations along the length of reinforcing bar were determined by means of chains of strain gauges pasted on the upper and lower faces of the reinforcing bar. According to the results of the study, the distribution of deformations along the length of reinforcing bars in the zone of transverse bending at different stages of loading is established. The experimental values of bending moments and shear forces in reinforcing bars after the formation of an inclined crack and in the failure stage were determined according to the readings of strain gauges. An analysis of the experimental data is performed and a comparison is made between the experimental values of the dowel action of the longitudinal reinforcement of reinforced concrete beams at the intersection of an inclined crack, depending on the percentage of longitudinal reinforcement of section.

1. Introduction

The strength calculation of inclined sections of bent reinforced concrete elements in the code of rules SP 63.13330.2012 [1] is carried out on the basis of the condition that the force from external loads transmitted to the section should not exceed the internal limit force in the inclined section. The internal limiting force in calculating the strength of inclined sections on the action of transverse forces is added from the shear force in the compressed concrete zone and the total force in the transverse reinforcement that cross inclined crack.

The shear force in the compressed zone of concrete $Q_b$ in the code of rules SP 63.13330.2012 [1] and ACI 318 [2] is determined by empirical relationships. The empirical dependence for the determination of $Q_b$ was proposed in [3], as a function of the concrete compressive strength and the projection length of an inclined crack. Subsequently, the compressive strength of concrete was replaced by its tensile strength, which improved the convergence of the calculated and experimental values.

Experimental studies carried out in [4] have shown that in the inclined section the forces not taken into account in the design model are acting: the shear force in the longitudinal tensioned reinforcement (dowel action) and the aggregate interlock forces along the edges of the inclined crack. The method of calculating the strength of reinforced concrete elements in inclined sections, taking into account the forces of the dowel action and aggregate interlock forces along the edges of the inclined crack was...
proposed by A. S. Zalesov [5]. However, in the normative method of calculation these efforts were not presented in the calculated dependences due to insufficient data and were taken into account indirectly — through the value of $Q_b$ [6]. The next stage in the development of the method for calculating the strength of flexural reinforced concrete elements along inclined cross sections was the proposal of the authors [7-12]. The calculated dependencies proposed in [8, 9] include the following forces: the total force in the transverse reinforcement crossing the inclined crack, the tangential force (dowel action) arising in the longitudinal tensioned reinforcement; forces of aggregate interlock along the edges of an inclined crack. The tangential force in the compressed zone of concrete is determined by the refined dependence [7], which allows to avoid additional restrictions of empirical nature, but in the strength condition the tangential force $Q_b$ is expressed through the other components of the stress state.

The estimation of the forces acting at the intersection of the longitudinal tensile reinforcement and inclined crack is a difficult task, since it depends on a large number of factors [13-17]. The experiments show that at the intersection with the inclined crack, the longitudinal reinforcement is exposed to both tension and bending, due to the mutual displacement of the parts of the beam separated by the inclined crack [18-20]. At the intersection of the longitudinal reinforcement and inclined crack in the rod occurs axial longitudinal tensile stress and transverse force, so-called dowel action, which, in turn, causes spalling or cracking of concrete cover layer [21, 22]. Transverse (dowel) force in the longitudinal reinforcement can be determined on the basis of limit state in the separation or cracking of the concrete cover layer, or on the basis of limit state in the reinforcing rod from the action of bending moment and axial tensile longitudinal force. Due to the insufficient amount of experimental data on the magnitude of the dowel effect in reinforcing bars under the action of transverse bending, the problem of accounting for the dowel effect in the calculation of the beam strength in the inclined section is still relevant.

2. Methodology
An experimental study of the dowel action of longitudinal reinforcement was carried out on two test samples. The samples were reinforced concrete beams of rectangular cross-section $h = 450$ mm, $b = 330$ mm, with a design span $l = 2000$ mm. The samples differed in the percentage of longitudinal reinforcement of the cross section (0.93% and 1.54%). Reinforcement of the beams was performed by two longitudinal reinforcement rods of class A500C (with a diameter of 28 mm for a beam of 2.5 B-0.93-28 and 36 mm for a beam of 2.5 B-1.54-36). The rods were welded on supports to the anchors – angle type rolling profile. Transverse reinforcement was absent in the samples.

To determine the deformation of concrete on its surface were glued strain gauges with a base of 50 mm. Gluing of the strain gauges was performed according to the standard procedure on the prepared surface. To determine the main deformations of concrete, two tensor grids were glued, which included three tensors in each shear span of the beam. The tensor grid is shown in figure 1.

![Figure 1. Scheme of strain gages location on concrete surface.](image)

Deformation of the reinforcing bars was measured using strain gauges with a base of 10 mm. The tensors were glued with a step of 100 mm to the prepared platforms on the upper and lower surface of the rods (figure 2).
After curing the glue, the waterproofing of the strain gauges was carried out with an epoxy composition (figure 3) for subsequent concreting of samples.

To determine the physical and mechanical characteristics of concrete, tests were carried out on concrete cubes and prisms made during the concreting of samples. The determination of the characteristics of reinforcement rods was carried out according to the results of testing the rod samples. According to the test results, the prismatic strength of concrete was $R_p = 22$ MPa. Tensile strength of reinforcement was $\sigma_u = 620$ MPa.

Loading of samples was carried out by concentrated force in the middle of the span, so that the relative value of the shear span was 2.5 (figure 4).

The load was applied in steps of 5% of the theoretical failure load. The time of holding the sample under load at each stage was 15 minutes. The destruction of the samples occurred on an inclined cross section from the action of transverse force and was fragile. Experimental values of destructive loads were:

- for sample 2.5 B-0.93-28 $P_{ult} = 333.5$ kN;
- for sample 2.5 B-1,54-36 $P_{ul} = 289,4$ kN.
The type of samples after the test is shown in figure 5.

![Figure 5. Type of samples after the test.](image)

3. Results and Discussion

According to the indications of strain gages on the reinforcing bars obtained during the tests, for a span with a critical inclined crack at a load $P \approx P_{ul}$ are presented: graphs of the distribution of relative deformations along the length of the rods, diagrams of bending moments and transverse forces in the cross sections of the rods near support zone of the samples. For figures 6 to 8 shows the experimental values of strains distribution and resulting diagrams efforts for a beam of 2.5 B-0,93-28.

![Figure 6. Strains distribution along the length of reinforcing bar.](image)

![Figure 7. Diagram of bending moments along the length of reinforcing bars.](image)

![Figure 8. Diagram of transverse forces along the length of reinforcing bars.](image)

**Beam 2.5 B-0,93-28.** The maximum value of transverse force is: $Q_{d,1} = 5.4$ kN, $Q_{d,2} = 4.7$ kN for rods number 1 and number 2, respectively. The value of transverse force for two rods $Q_{d,tot} = 10.1$ kN. The value of transverse force, which is perceived at the destruction of the beam is $Q = 166.75$ kN.
Comparison with the value of transverse force perceived by the beam, shows that the magnitude of dowel action is \( Q_d = 6\% \) of the bearing capacity of the beam.

**Beam 2.5 B-1,54-36.** The maximum value of transverse force is: \( Q_{d,1} = 14.7 \text{ kN}, Q_{d,2} = 14.9 \text{ kN} \) for rods number 1 and number 2, respectively. The value of transverse force for two rods \( Q_{d,\text{tot}} = 29.6 \text{ kN} \). The value of transverse force, which is perceived at the destruction of the beam is \( Q = 144.55 \text{ kN} \). Comparison with the value of transverse force perceived by the beam, shows that the magnitude of dowel action is \( Q_d = 20.5\% \) of the bearing capacity of the beam.

4. **Conclusion**

The results of the study have a good correlation with the results of the study of the dowel action performed by the author [21, 22]. The results of study [21] show that the magnitude of dowel forces in reinforcement depend on resistance moment of reinforcing bars. For beams, reinforced rods with a diameter of 22 mm, dowel force of longitudinal reinforcement in an inclined cross-section, according to [21], is 5% of the bearing capacity of the beams by a transverse force.

An experimental study of magnitude of the dowel force of longitudinal reinforcement in the inclined cross section of reinforced concrete structures will create a database and move to an analytical evaluation of this effort. Various proposals for estimating the amount of dowel force in longitudinal reinforcement are presented in [23-25]. However, the lack of experimental data restrains their practical application in improving the standard methods for calculating the strength of reinforced concrete structures along inclined cross sections in the zone of transverse bending.

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