The shear span influence on the crack formation and fracture features in the experimental samples in the external conditions of composite reinforcement presence or absence

A A Shilov*, P A Shilov, A V Shilov
Don State Technical University, 162, Socialisticheskaya str., Rostov-on-Don, 344022, Russia

E-mail: ale381420082008@yandex.ru

Abstract. The results of the cracking and fracture process investigations in the inclined sections of the reinforced concrete beams, in the conditions of reinforcement presence or absence in the supporting areas with the triangular U-shaped carbon fiber clamps, are presented. The impact of a slice span of 1.5h₀, 2.0h₀ and 2.5h₀ is estimated, as well as the presence of composite reinforcement, on the inclined cracks’ formation and development features.

Introduction
Composite materials in the form of fiber-reinforced plastics are used more and more intensive every year in the construction industry. In the past two decades, the reinforced concrete structures with external composite reinforcement have become a popular method of rebuilding and increasing their bearing capacity. Due to such advantages of composite materials as high tensile strength with low weight of the reinforcing elements, high modulus of elasticity, corrosion resistance, simplicity and manufacturability of the reinforcement process itself, this method is increasingly being used in cases where reinforcing concrete structures with concrete and steel has certain risks.

Since 2012, a large-scale study work devoted to the reinforced concrete structures with internal and external composite reinforcement has been conducted at the Department of Reinforced Concrete and Stone Structures of DSTU. In particular, comprehensive studies of the reinforced concrete structures reinforced with round glass and carbon fiber reinforcement were carried out [1-4]. A study of the strength of sections of reinforced concrete beams normal to the longitudinal axis of the element reinforced with external composite reinforcement was performed [5]. The studies of the compressed reinforced concrete elements reinforced with the composite materials at various eccentricities of load application have been completed [6–9]. The reinforced concrete beams sections’ studies inclined to the longitudinal axis of the element have been completed, reinforced with external composite clamps in the conditions of the initial inclined cracks presence or absence [10-14].

The Code of Rules CR - 164.1325800.2014, released in Russia and dedicated to the reinforcement of the reinforced concrete structures with the composite materials, gave the basic provisions and recommendations for the composite reinforcement elements’ calculation and design. However, along with this, an additional incentive to conduct the research in this area was given, as some questions remained unanswered. Among them, attention is drawn to the question of possible differences in the shear span influence on the inclined cracks and fracture’s formation along an oblique section in the beams that do not have an external composite reinforcement, and in the beams reinforced in the supporting sections with the composite transverse clamps of various designs. The fact is that the external transverse clamps can have a significant impact on the nature of the inclined cracks’ formation and the fracture nature along the inclined section, which is not taken into account in the calculations to the proper extent.
This article is devoted to the study of the various spans influence of a load shear and various types of composite clamps on the crack formation features in the inclined sections of the reinforced concrete beams and their destruction.

Materials and methods
For the experiments, the testing beams 2.0 m long and 125 x 250 mm section were made. The samples were made of heavy concrete class B30 and had the same steel reinforcement. Working fittings were adopted from 2Ø18 A500, the structural reinforcement of the compressed zone from 2Ø6 B500, and the transverse reinforcement was adopted in the form of closed knitted clamps Ø3 B500, installed with a pitch of 150 mm (Figure 1).

![Figure 1. The prototype frame design.](image)

A total of 24 experimental beams were tested, 6 of which were standard and had no composite reinforcement, and 12 were reinforced with the U-shaped composite clamps. The external composite clamps were made of carbon fabric with a thickness of 0.166 mm and the strength of one layer, according to the test samples’ results, 3200 MPa.

![Figure 2. Amplification scheme of the experimental beams with tripartite U-shaped clamps.](image)

All prototypes were tested at three different ratios a/h₀ – 1.5, 2 and 2.5.

During the test, in order to ensure destruction along the inclined section, the supporting section opposite to the test was reinforced with a steel cage, according to the diagram in Figure 3.

All prototypes were tested in a stepwise increasing load according to the scheme of a single-span articulated beam loaded with two concentrated forces. The crack opening width was determined using an MBP-3 measuring microscope, with a division value of 0.02 mm, and was additionally controlled using the metal probes. The observation had been carried out until the destruction of the prototype in an inclined section became obvious.
Results
The test results for the beams inclined sections’ strength are given in Table 1. The process of formation and opening of the inclined cracks in the reference and reinforced beams is reflected in the diagrams in Figure 7.

As shown by the experimental studies’ results, the external composite reinforcement in the form of U-shaped clamps has a significant effect on the shape and nature of the studied beams’ destruction at the inclined sections. A different effect on the cracking and strength nature was exerted by different values of the shear span during the samples’ testing.

The destruction of the prototypes reinforced with U-shaped clamps can be divided into three most characteristic types:

1) Cross-cut test \(a=1.5h_0\). Rupture of the first clamp and separation of the second coarse aggregate. The destruction has a sharp instantaneous nature and occurs due to the rupture of the first clamp and the separation of the second clamp. Concrete under the force application point during destruction is cut off. The rupture of steel transverse reinforcement and significant inelastic deformations of steel working and structural reinforcement were noted. The reinforced prototypes’ destruction in the first form (1.5\(h_0\)) is presented in Figure 4.

![Figure 4](image)

**Figure 4.** The destruction nature of the prototype, reinforced with U-shaped clamps during the section’s case bay 1.5\(h_0\) (view №1).

2) The section’s case bay test \(a=2.0h_0\).

Rupture of the first and third clamps, separation of the second clamp. During the destruction, the first clamp, located at the support, and the third clamp, at the point of the force application, the composite clamps broke at the point of their intersection with an inclined crack, the second, located between them, the clamp was torn off with concrete. Concrete under the force application point was cut off. The gap of steel transverse reinforcement is noted. The destruction of reinforced prototypes in the second form (2\(h_0\)) is presented in Figure 5.

![Figure 3](image)

**Figure 3.** The test beam pattern.
Figure 5. The destruction nature of the prototype, reinforced with the U-shaped clamps during the section’s case bay 2,0h₀ (view №2).

3) The section’s case bay test a=2,5h₀.

The gap of all three composite clamps. During the destruction, all three clamps on both sides of the beam broke, which indicates the full inclusion of the composite clamps in the work during the entire test. Concrete under the point of application of force was cut off. Steel working and structural reinforcement received inelastic deformations; steel transverse clamps broke. The destruction of reinforced prototypes in the third form (2,5h₀) is presented in Figure 6.

Figure 6. The destruction nature of the prototype, reinforced with the U-shaped clamps during the section’s case bay 2,5h₀ (view №3).

Table 1. The test results of the experimental beams on the inclined sections’ strength

| № p/p | The section’s case bay | Beam Code | Inclined crack load Q_{rec.} [kN] | Breaking load Qₜ [kN] |
|-------|------------------------|-----------|----------------------------------|----------------------|
| 1     | 1.5h₀                  | Ba-1      | 35                               | 112.0                |
| 2     | 2h₀                    | Ba-2      | 35                               | 93.5                 |
| 3     | 2h₀                    | Bb-1      | 25                               | 90.0                 |
| 4     | 2h₀                    | Bb-2      | 35                               | 94.25                |
| 5     | 2.5h₀                  | Be-1      | 25                               | 81.3                 |
| 6     | 2.5h₀                  | Be-2      | 25                               | 74.5                 |
|       |                        |           |                                  |                      |
|       | Reference samples      |           |                                  |                      |
| 7     | 1.5h₀                  | 5BSa-1-X1 | 15                               | 105.0                |
| 8     |                         | 6BSa-2-X1 | 20                               | 102.0                |
| 9     |                         | 1BSa-1-X1 | 35                               | 110.0                |
| 10    |                         | 2BSa-2-X1 | 35                               | 130.5                |
| 11    |                         | 5BSa-1-X1 | 20                               | 130.0                |
| 12    |                         | 6BSa-2-X1 | 25                               | 135.0                |
Summary

Analyzing the results, we can note the following:

The first inclined cracks formed at a load level in the range from 15 to 45 kN. Moreover, the inclined cracks development nature depended strongly on the magnitude of the shear span. So when the span is equal to 1.5$h_0$, an inclined crack, along with an increase in horizontal projection, was actively developed in vertical projection, which led to a violation of the required length of anchor clamp in the middle of the section’s case bay and exit from the work of the clamp at the point of force application. With the section’s case bay 2.0$h_0$, all three composite clamps were fully involved, and the crack, in the process of the load increasing, was steadily developed from the support to the point of the force application. With the section’s case bay 2.5$h_0$ in a number of cases, at the early stages of loading, the development of two separate inclined cracks was noted between the composite clamps, which at later stages were combined into one crack, along which a fracture occurred. It is important to note that for all the shear span values, the fracture passed along a crack going from the support to the force application point.

| 13 | $2h_0$ | 3BSb-1-X1 | 15 | 113.6 |
| 14 | 4BSb-2-X1 | 20 | 134.5 |
| 15 | 3BSb-1-X1 | 35 | 115.0 |
| 16 | 4BSb-2-X1 | 45 | 108.0 |
| 17 | 3BSb-1-X1 | 45 | 139.0 |
| 18 | 4BSb-2-X1 | 45 | 125.0 |
| 19 | $2.5h_0$ | 1BSc-1-X1 | 25 | 101.3 |
| 20 | 2BSc-2-X1 | 35 | 93.25 |
| 21 | 5BSc-1-X1 | 25 | 109.45 |
| 22 | 6BSc-2-X1 | 35 | 107.0 |
| 23 | 1BSc-1-X1 | 25 | 105.0 |
| 24 | 2BSc-2-X1 | 35 | 105.0 |

*Q, kN*
b) \( Q, \text{kN} \)

![Graph showing force vs. eccentricity for different curves labeled 1 to 13]

\[ a_{ecc}, \text{mm} \]


c) \( Q, \text{kN} \)

![Graph showing force vs. eccentricity for different curves labeled 1 to 13]

\[ a_{ecc}, \text{mm} \]
Figure 7. Graphs of the dependence of the crack opening width on the increase in load for the reference samples (a), the samples tested during the section’s case bay 1,5h₀ (b), 2,0h₀ (c) and 2,5h₀ (d).

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