Analysis of adhesion factors of the external reinforcement and base surface of the bent concrete element

Oleg Simakov¹ and Aleksandr Simakov²

¹ Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, Russia
² Federal Government Budget Institution “All-Russian Research Institute for Civil Defense and Emergencies of the Ministry for Emergency Situations of Russia” (Federal Center of Science and High Technology), Davydkovskaya str., 7, Moscow, 121352, Russia

E-mail: simakovoa@mgsu.ru

Abstract. The development of reinforcement technology for existing reinforced concrete structures requires more accurate and careful consideration of various reinforcement parameters. Refinement of the calculation theory, coefficients, and the introduction of additional criteria make possible to strength structures with greater efficiency. One of the ways to increase the effectiveness of external reinforcement accounting, in fact, increasing the calculated value of the load-bearing capacity of the reinforced section, is consideration the anchoring of the reinforcement element. Currently used methods for calculating the strength of bent elements take into account the coupling of external reinforcement with the surface of the reinforced element by limiting deformations. At the same time, if it is possible to take into account the anchoring of the external reinforcement, both the calculated and the actual bearing capacity of the reinforced element is increase. There’s an analyzes the factors that determine the anchoring of the external reinforcement, which affect the load-bearing capacity of the reinforced normal section of the reinforced concrete element. The analysis is based on previous experimental studies, as well as numerical modeling of the distribution of shear forces. The simulation was performed on a single-span reinforced concrete beam with a hinged support. The numerical simulation took into account the nonlinear nature of the deformation of reinforced concrete (reinforced element), as well as the binding external reinforcement. The work of the outermost reinforcement (carbon fibers) was considered linear, since the graph of deformation of the carbon fiber is almost a straight line before destruction.

1. Introduction

Composite materials for reinforcing reinforced concrete and stone structures have been used for more than 40 years, and so far the full potential of this strengthening method has not been realized. This is due at first to the limited coupling of the reinforcement system with the surface of the element being reinforced, and its anchoring in the body of this element. Improving the anchorage of the external reinforcement will increase the design stress in the reinforcement system and, as a result, in most cases, increase the load-bearing capacity of the reinforced section. In addition, anchoring elements of external reinforcement allows you to implement non-typical schemes for strengthening structures that
were not previously used, for example, strengthening inclined sections of edges with low height, strengthening elements with limited access to the surface of the reinforcement.

The method of calculating the load-bearing capacity of normal sections of bent reinforced concrete elements by strengthening with external reinforcement is based on empirical dependencies that do not allow the destruction of the reinforced element [1-5].

In General, the mechanism of destruction of bent reinforced elements can be defined as:

- Destruction of a reinforced concrete element on concrete (Figure 1a)
- Destruction of external reinforcement (Figure 1b)
- Structural failure with reinforcement (a complex term describing the options for destruction, actually peeling the external reinforcement on the adhesive layer or with a layer of concrete: the beginning of detachment at the end of the element, the beginning of detachment in the zone of normal cracks, the beginning of detachment in the zone of inclined cracks (Figure 1c).

![Figure 1. Types of destruction of strengthened elements](image)

2. Anchoring of FRP

Anchoring the external reinforcement is one of the key issues related not only to the reliability of the reinforced element, but also to the calculated load-bearing capacity. The studies carried out so far have allowed us to study the issue of the element's load-bearing capacity, i.e., until the moment of destruction. At the same time, in the course of conducting experimental studies with the participation of the author of the article, it was noticed that visible deformations of the external reinforcement elements occur at the ends of the reinforced elements until the samples are destroyed.

The main generally accepted method for calculating the normal cross sections of flexed reinforced concrete elements is the [2, 4] method, according to which the calculation of the load-bearing capacity of flexed reinforced concrete elements is based on limiting the deformation of the external reinforcement. The basic formula (1).
where $E_f$ - elastic modulus of FRP, $\varepsilon_{fe}$ - calculated (permissible) deformations of external reinforcement, defined in general by the formula:

$$\varepsilon_{fe} = 0.41 \frac{R_{fu}}{nE_f}$$

where $R_f$ - the strength of the external reinforcement determined by the standard (experimental) value, taking into account the reliability coefficients, $n$ - the number of layers, $t$ - the thickness of the layer in mm.

The coefficient 0.41 takes into account the coupling in the anchorage zone. In fact, this is an empirical coefficient obtained from the results of numerous various tests. It is possible to increase this value by increasing the anchorage (we are talking about maintaining the existing calculation method and its corresponding prerequisites and restrictions).

To date, a sufficient number of experimental studies have been carried out to assess the maximum loads on the external reinforcement. The analysis conducted earlier tests shows that the existing

---

**Figure 2.** Types of anchoring. a) U-wrap FRP-sheet anchor system; b) mechanical anchor; c) fiber anchor
method of calculation of external reinforcement prevents separation of the ends of the outer reinforcement and deformations in the contact area of the external reinforcement of concrete [6-14].

For the purpose of anchoring the external reinforcement, the following additional anchoring options are currently used (Figure 2).

Despite the accumulated experience of using anchors, as well as the efficiency confirmed by experiments, there is currently no method for calculating and constructing an anchorage.

In the development of this technology and its justification was to analyze influence of the following factors on the distribution and the value of shear along the border of the contact faces of the concrete section, and external reinforcement:
- loading level (the curvature of the amplified element, provided that the initial curvature is zero);
- loading level (the curvature of the reinforced element, provided the initial curvature corresponding to the moment of crack formation).

3. Modeling
Mathematical modeling was carried out on a single-span beam with a span of 5 m. the section of 400x600 mm with the lower reinforcement 4ø16 and the upper 4ø12 was considered. The reinforced beam and external reinforcement were modeled by rod elements, while the connection was carried out by elements with a higher order of stiffness.

![Figure 3. Model](image)

An important and determining factor in modeling is the determination of external reinforcement parameters. In fact, you must consider the following parameters separately:
- stiffness of the amplified element (nonlinear operation) - Fig. 4a;
- stiffness of reinforcing fibers (you can assume linear operation) - Fig 4b;
- stiffness of the binder-adhesive composition (non-linear operation) - Fig 4c.

These diagrams are based on the results of actual tests of elements.
Based on these diagrams, the following graphs of shear forces for the concrete-external
reinforcement contact zone were obtained using the iteration method (determination of forces-
correction of stiffness by forces) (Figure 5).

Conclusion on the results obtained. There are three types of distribution of effort:
1. With bending forces up to 80-90% of the moment of crack formation (at this stage of
research, the moment of crack formation is defined as a criterion for the distribution of
forces), the distribution of shear forces across the adhesive layer is relatively uniform, with a
slight increase at the ends of the reinforcement element;
2. With forces approximately corresponding to the moment of crack formation, a jump
in shear forces at the ends of the reinforcement element begins to be clearly distinguished.
3. With increasing efforts in the element of effort more the moment of crack formation,
is an increase in shear in the adhesive layer in the area between the border of cracking and the
end reinforcement. At the same time, the shear forces in the Central part grow slightly.
4. Conclusion

Based on the results of mathematical modeling, the following conclusions can be drawn about the use of external reinforcement based on carbon fibers to strengthen the normal cross-sections of bent reinforced concrete elements:

1. The distribution of shear along the contact system of strengthening/reinforcing the surface structure is not uniform and depends on the following parameters: Flexural rigidity of the reinforcing element (changing under load), the stiffness of the adhesive layer in shear and the stiffness of the reinforcement (the basic parameters according to the techniques [2, 4, 5]), and probably some additional parameters, such as initial cracks, the effect of which in the present work is not defined;

2. During operation, the distribution of shear forces along the contact boundary external reinforcement-beam surface changes due to changes in the stiffness of the epoxy binder. However, as a rule, there is no significant change in loads during this period;

3. The effect of the initial deflection on the distribution of tangent shear forces is not analytically confirmed.

4. It is necessary to recommend anchoring only the ends of the reinforcement elements in all cases of strengthening the normal sections of the bent concrete elements. At the same time, it is also desirable to perform anchoring activities on the border of the crack formation zone.

5. According to the results of the analysis of the conducted experimental studies, at the moment the most reliable anchor elements of the mechanical type (steel elements), as well as composite tapes that preserve the directional structure of the fibers (single and bidirectional tapes, carbon bundles of small diameter).

6. It is necessary to conduct special research, including experimental studies, in order to determine the quantitative indicators of the influence of external reinforcement parameters on the level of shear force transfer when strengthening the bent elements, as well as the basic criteria for the deformability of the anchor fastener.

References

[1] Tamrazyan A.G., Fedorova N.V. 2016 Ocenka nadezhnosti zhelezobetonnyh konstrukcij, usilennyh ugleplastikovym vneshnim armirovaniem. Izvestiya vysshih uchebnyh zavedenij. Tekhnologiya tekstil'noj promyshlennosti. № 6 (366). S. 226-231

[2] ACI 440.2R-17. Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures.

[3] Breveglieri, M., Barros, J. A., Dalfré, G. M., & Apriile, A., 2012. A parametric study on the effectiveness of the NSM technique for the flexural strengthening of continuous RC slabs. Composites Part B: Engineering, 43(4), 1970-1987.

[4] Muhamediev T.A. Kuzevanov D.V., 2013 Raschet po prochnosti normal'nyh sechenij zhelezobetonnyh konstrukcij, usilennyh kompozicionnymi materialami. Beton i zhelezobeton, №6 S.

[5] Orton, S. L., Jirsa, J. O., And Bayrak, O., CFRP for Continuity in Existing RC Buildings Vulnerable to Collapse, ACI Structural Journal, V. 106, No 5, 2009

[6] Silva, P. F., & Ibell, T. J., 2008. Evaluation of moment distribution in continuous fibre-reinforced polymer-strengthened concrete beams. ACI Structural Journal. 105(6), pp. 729-739.

[7] Abbas Tajeddini et al 2016 Quantifying moment redistribution in FRP-strengthened RC beams Structures & Buildings May 20-24

[8] Kim, S.J., Jirsa J.O. and Bayrak, O. Use of Carbon Fiber-Reinforced Polymer Anchors to Repair and Strengthen Lap Splices of Reinforced Concrete Columns // ACI Structural Journal. – 2011. – 108(5). – PP 630–640.
[9] Sergio F. Breña, Geoffrey N. McGuirk. Advances on the Behavior Characterization of FRP-Anchored Carbon Fiber-Reinforced Polymer (CFRP) Sheets Used to Strengthen Concrete Elements // *International Journal of Concrete Structures and Materials*. – 2013. – Vol.7, No.1. – PP.3–16.

[10] Niemitz, C. W., James, R., & Breña, S. F. Experimental behavior of carbon fiber-reinforced polymer (CFRP) sheets attached to concrete surfaces using CFRP anchors // *Journal of Composites for Construction*. – 2009. – V.14, No 2. – PP.185–194.

[11] Lee, J.-H.; Chacko, R.M.; And Lopez, M.M., Use Of Mixed Mode Fracture Interfaces for The Modeling of Large Scale FRP Strengthened Beams, *Journal of Composites for Constructions*, 2014

[12] S.A. Zenin, R.SH. SHaripov, O.V. Kudinov. Issledovanie raboty ankerov iz uglomerodnykh zhugutov dlya usilieniya zhelezobetonykh konstruktsij i razrabotka obshhikh pravil proektirovaniya // *Vestnik NITS «Stroitel'stvo». – 2017. – №4(15). – S. 28-36.

[13] О.А. Simakov, S.A. Zenin, O.V. Kudinov, P.V. Osipov. Issledovanie raboty na vyryv ankerov na osnove uglomerodnyh volokon pri ustrojstve sistem vneshnego armirovaniya // *Promyshlennoe i grazhdanskoе stroitel'stvo*. – 2019. – №3. – S. 48-53.

[14] О.А. Simakov, S.A. Zenin, O.V. Kudinov, P.V. Osipov. Rabota na srez ankerov na osnove uglomerodnyh volokon pri vneshнем armirovani // *Promyshlennoe i grazhdanskoе stroitel'stvo*. – 2019. – №9. – S. 59-63.