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PRECONDITIONS OF COMPUTATIONAL MODEL OF THE BENDING STRENGTH OF REINFORCED CONCRETE STATICALLY INDETERMINATE BEAMS WITH HYBRID REINFORCEMENT

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In this article, the variant of application of composite reinforcement together with metal (hybrid reinforcement) in bent statically indeterminate reinforced concrete elements is considered. The advantages and prospects of application of this type of reinforcement are shown. The possibility of using a block model for calculating the strength of elements with hybrid reinforcement is considered. The assumed assumptions for the calculation model are determined and the calculation algorithm is presented.

At present, nonmetallic composite reinforcement is finding increasing use in construction, which in international practice is customary for designating FRP – *fiber reinforced polymer composite* [1–3]. In particular, such reinforcement is widely used in the erection of concrete objects, exploited in aggressive environments, special purpose structures. However, it is worth paying attention to the fact that certain difficulties are hindering the wide introduction of this type of reinforcement. Among them, one can note the absence of unified requirements of state or international standards for the mechanical properties of composite rods and methods for calculating structural elements reinforced with composite reinforcement, unified requirements for quality control methods and rules for rod acceptance. In addition, a number of negative properties of the composite play a significant role in the use of composite fittings (glass, basaltic and aramid fibers): low fire resistance, low modulus of elasticity, and low alkali resistance, on which the durability of the designed structure will depend.

Recently, more attention has been paid to the problem of developing effective solutions for the application of composite rods in bent reinforced concrete elements, which do not require additional costs for eliminating the main disadvantages of the composite. To date, even high tensile strength (more than 1000 MPa) does not allow solving the main problem of using composite reinforcement as working (with a complete replacement of steel) in reinforced concrete constructions, namely the low value of the modulus of elasticity (about 50 GPa). Investigations in this field [4-6] have shown that when a reinforced concrete bending element is reinforced solely with composite reinforcement, after the formation of normal cracks, there is practically no plastic deformation zone and, consequently, the destruction of this type of elements is fragile. Thus, the use of composite reinforcements in bent elements without prior strain is impractical today. It is worth paying attention to the fact that the prestress of nonmetallic reinforcement causes great technological difficulties: from the method of tension to the development of reliable anchors.

The situation can be greatly improved by using a composite and metal reinforcement in the stretched zone of the reinforced concrete element (the so-called hybrid or combined reinforcement). Experimental studies [7] of statically determinate beams with combined reinforcement made it possible to obtain the plastic form of the destruction of the element. In addition, the authors noted that the plastic deformation of the structure, even with a minimal introduction of composite rods, proved to be substantially longer than for the elements reinforced solely by metal reinforcement. The analysis of the test results [7] suggests that even a small amount of composite reinforcement, which will work in the elastic stage, can have a positive effect in the operation of statically indeterminate bins. This effect can be achieved in terms of more rational redistribution of effort. The expected favorable result from the use of hybrid reinforcement will allow expanding the field of application of composite reinforcements without preliminary tension.

The issue of calculating reinforced concrete elements with composite reinforcement does not lose relevance. In international practice, thanks to extensive experimental and theoretical research conducted in recent years, the basic principles and recommendations for calculating and designing structures with composite fittings have been developed [1–3]. However, in work [8] the authors note that the use of composite reinforcement in a structural element in conjunction with steel requires a significant adjustment of the design models. The most promising and possible solution to such problems is the so-called block calculation model. In general, for statically indeterminate reinforced concrete beams with metal reinforcement, this model [9] considers a block element separated by two adjacent cracks. The solution to the problem in the general case is reduced to the solution of the system of equations based on the positions of the modified deformation model, which includes the equations of the equilibrium of longitudinal forces, moments and the equilibrium equation for an individual rod, the slip equations. In addition, the deformation diagrams of the materials used and the diagrams linking the values of tangential stresses and the values of slippage (mutual displacement) supplement the system of equations. A detailed algorithm for calculating static-indeterminate beams with metal reinforcement is presented in [9].

It should be noted that the key role in the design model is given to the "tangential stresses-slippage" diagram, which is essentially the law of the coupling of the reinforcing bar and concrete. For steel reinforcement, the parametric points of this diagram are taken according to the instructions of ModelCode 2010. The diagram of the adhesion law for composite reinforcement is also specified in MC 2010, but the values of the parametric points must be obtained experimentally for a specific type of reinforcement. One of the solutions to this problem can be considered the results of extensive studies under the leadership of Gaitano Manfredi [9–13], in which the averaged values of the parameters of points on the diagram "tangential stresses – slippage" for GRP rods were obtained.

Thus, to solve the problem of developing a computational model of bent elements with hybrid reinforcement, all the necessary initial data are available. However, to implement the calculation, it is necessary to determine the total averaged parameter, which in the end will be the criterion for the termination of the iterative calculation process [14]. After the successful realization of this, the distribution of the relative deformations of the stretched concrete and reinforcement will be obtained for the entire element, which in the future will allow us to calculate the value of the curvature distribution in all necessary cross sections along the length of the block. If we consider an example with metal or fiberglass reinforcement, the criterion for the termination of the iterative process is the attainment of the relative deformations of the stretched-zone concrete in the cross-section of the bent element of the limiting values. This indicates the formation of a new crack or relative deformations of the stretched concrete of the relative deformations values of the stretched armatures, which indicates the beginning of the joint deformation zone of the reinforcement and the concrete. Thus, in case of termination of the iterative process at each of its steps, we obtain the slip values of the reinforcing bar relative to the concrete, and subsequently the resulting displacement is the basis for calculating the strength of the entire element. Nevertheless, there are a number of certain difficulties: if we look at the diagram of the adhesion law for metal and fiberglass reinforcement in numerical terms, it is obvious that the materials are displaced in concrete in completely different ways (Fig. 1).

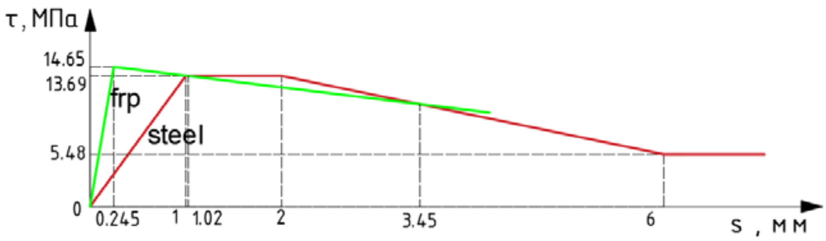

Fig. 1. Laws of adhesion of fiberglass and metal reinforcement with concrete

The situation is similar to the diagram of deformation of these materials (Fig. 2).

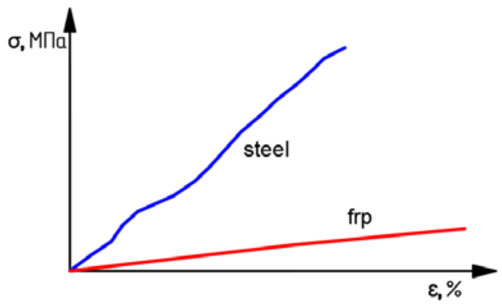

Fig. 2. Material deformation diagram

One possible solution to the presented problem can be obtained by equating effective zones of stretched concrete between metal and composite bars. Thus, when implementing the iterative process, the following assumption should be adopted: the concrete of the stretched zone of the bent element is deformed equally throughout the area.

When implementing the iterative calculation process, one-time deformation of metal and composite rods will be considered according to the algorithm for calculating the block fracture model. Having adopted the above assumption, in the first step of the iterative process, the tensile stresses in the concrete, which in turn depend on the tensile forces and the stresses in the reinforcing bars corresponding to them, will be equated and their average value determined. Based on the obtained average value of the stress, the relative deformations of the concrete will be the same for sections with metal and composite rods. The value of the relative deformations of concrete will allow us to determine the values of tangential stresses in reinforcing bars and the displacement of concrete rods in concrete.

In the second and the subsequent stages of the iterative calculation procedure, the following algorithm will be repeated: the stresses in concrete for the sections with metal and composite reinforcement are determined, their mean value is derived, and the relative deformations in the stretched concrete are determined. Further, on these values all the necessary parameters of the considered site are calculated. The criteria for the termination of the iterative process will be similar to the standard calculation criteria for a block fracture model of the bent elements with metal or composite reinforcement.

The proposed computational model of bent statically indeterminate reinforced concrete elements with hybrid reinforcement will allow expanding the application area of composite reinforcement without prestressing.

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