408. Fiber concrete beam failure observed as rare phenomena

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Abstract. Investigation of various dynamical natural and technical phenomena is closely connected with studying general nonlinear phenomena characterizing the behavior of dynamical systems. In recent years much attention has been paid to studying new nonlinear effects which can be used in vibro-technique, even in simple systems. Such systems happen to have complicated dynamics which has not been studied sufficiently yet. Fiber concrete beam failure always can be observed as rare phenomena because of existence of considerable dispersion of strength. The aim of this paper is to obtain function described stiffness of fiber concrete beam in the first stage (beam without crack) and at post-cracking stage (beam with crack).

Keywords: fiber concrete, rare phenomena, beam failure, pull-out laws.

1. Introduction

Adding fibers to concrete we can expect additional benefits and safety improvements: increase stiffness, flexural and tensile strength, impact resistance, as well as post-cracking stiffness. The use of steel fibres in concrete instead of traditional reinforcement is beneficial mostly due to simpler casting procedure. Technologically it is rather difficult to distribute a large content of steel fibres into the concrete mix because it negatively affects the workability. Therefore for the aim of good workability of the mix, steel fibres are limited both by their maximal content and length. So follows types of steel fibres have been used for specimens – straight fibres, fibres with end hooks (Dramix), and corrugated form fibres (Tabix).

For traditionally reinforced concrete structures the post cracking behaviour is based on tensile strength mechanism (of steel reinforcement rebars) for steel fibre reinforced concrete (SFRC) structures it is the pull-out mechanism of steel fibres that determines the load bearing capacity of the cracked material. Therefore it is important to perform a detailed micro-mechanical investigation of fibre pull-out process in order to understand and characterise the behaviour and crack propagation in SFRC structural elements. The investigation of pull-out mechanism for different type of steel fibres was performed for three types (with different geometrical form).

2. Principles of the proposed model

Experimentally obtained pull-out laws (see Fig.1) were used as the main input data for a newly proposed model [1-3] with the goal to predict linear and non-linear behaviour of SFRC beams under bending loads. Beam subjected to four point bending is observed in the study as shown in Fig.2. SFRC beams with dimension 15x15x60 cm were cutted by diamond saw at the depth of 1 cm forming the notch on the bottom side of each beam. The span length between underneath beam supports L_S=50 cm and the distance between symmetrically applied loads L_P=15cm. The main aim of the proposed model is to predict crack mouth opening displacement δ (crack is starting from the notch) depending on applied bending load P, simultaneously obtaining load – prism upper surface midpoint vertical deflection curves.

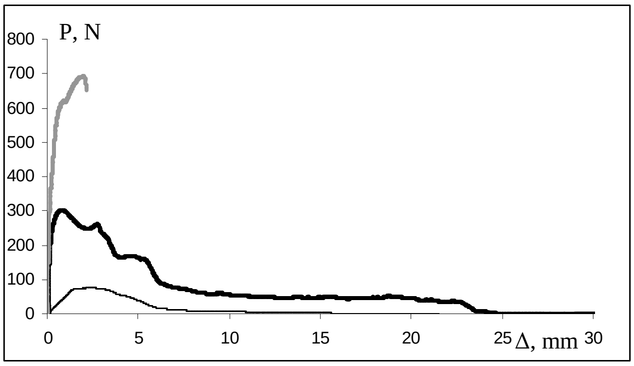

Fig. 1. The pull-out process of different form steel fibers
——— - Straight fiber;
▬▬ - Dramix fiber;
▬▬ - Tabix fiber.

Increasing the load is applied to the beam the cracking process is starting. Micro cracks are growing and linking forming large cracks till the moment then one or more macro crack (in our case crack was started from the notch) is crossing whole tensioned part of the beam crossection. After the formation of the crack the tensile load is still transferred through the crack by the fibres (the bridging effect). Because the fibres are being pulled out of the concrete matrix the ability of the SFRC beam to carry the applied load in the post-cracking state purely depends on the capacity of fibres in broken crossection to carry pull-out loads. At the same moment number of fibres crossing the crack surface is depending on fibre volume fraction in the material. According to the pull-out curves, were obtained, it follows that only for very small values of

δ fibre resistance is increasing (especially for straight and Dramix fibres), and after reaching the maximal value (see. Fig.1.), fibre resistance to withstand pull-out loads starts to decrease and thus decreases the load bearing capacity of the whole beam's broken crossection.

In the model the behaviour of SFRC beam was simulated by calculating internally existing load bearing value of each fiber crossing the crack (using this fibre experimentally measured pull-out curve), depending on crack opening value b_i at the location of this particular fiber (see Fig.5.). Firstly, it was assumed that the total crack height is constant regardless of size of the crack opening δ_i. This assumption was based on and determined from experimental testing results of SFRC beams performed parallel to this parametric study. Thus it was found acceptable for the crack height being assumed equal to $0{,}8$ of the total beam cross-section height H. As it can be seen from Fig. 3 the crack surfaces have been assumed as a plane therefore the local crack opening b_i can be simply geometrically determined from corresponding maximal crack opening δ_i.

The procedure of modelling beam behaviour in bending was performed according to step sequence, with the maximal crack opening δ_i values within the range from 0.2 to 6 mm with the step 0.2 mm.

At each step "i" with the corresponding maximal crack opening δ_i, firstly the local crack opening b_i is calculated as a function of distance y_n:

$$b_i = f(y_n)$$

As the local crack opening b_i is known at each distance y_n, the force p_i transferred through the crack can be calculated by using previously obtained fibre pull-out laws. However, this is the point when the factors of fibre embedded length, fibre volume fraction V_m, fibre orientation angle α (to the crack's surface) should be evaluated, thus referring to actual properties of the material observed. The volume fraction V_f of each fibre type could be easily determined from corresponding fibre weight fraction W_f. Further, number of each type of fibers on one crack's surface was determined, as the average fibre amount crossing the crack plane with chaotic fibers orientation and embedded length distributions (modeling results were compared with performed direct experimental measurements). The influence of fibre type, fraction and orientation actually can be summarized within one coefficient, which in this case is defined as fibre factor k_f:

$$k_f = \frac{2}{3} f(l, d, V_f, \alpha)$$

where 2/3 – is correction coefficient.

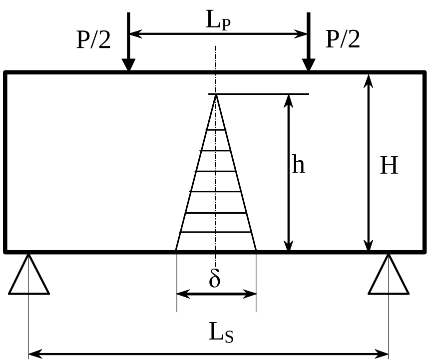

Fig. 2. Fiber concrete beam under the four point bending test

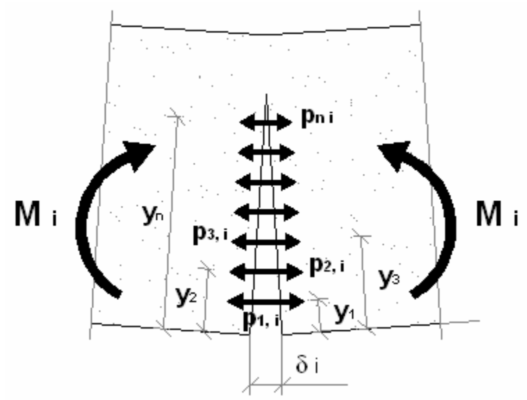

Fig. 3. Scheme of internal forces and moments formed in fiber concrete beam at post-cracking stage

Now the internal force transferred through the crack can be calculated. From the pull-out curves the force $p_{n,i}$ corresponding to a particular crack opening b_i can be determined all along the crack height as schematically depicted at Fig.3. As it can be seen in the figure the internal force $p_{n,i}$ was calculated at corresponding value of coordinate y_n.

$$p_{n,i} = f(y_n, \delta_i)$$

From the calculated values of internal forces $p_{n,i}$, resulting bending moment M_i can be determined corresponding to each crack opening value δ_i. According to accepted modelling assumptions it follows that:

$$M_i = \sum_{n=1}^{m} 2 \cdot p_{n,i} \cdot (0{,}8 \cdot H - y_n)$$

When the internal bending moment value is known, the corresponding external force P_i can be calculated from the equilibrium relations according to the scheme (Fig 5.):

$$P_i(\delta_i) = 2 \cdot M_i / L$$

where L is the span length of the beam. Relation of externally applied load P as a function of crack opening displacement δ is thus obtained at each step and can be represented graphically. The force P represents total force applied to the beam that is divided in two symmetrical forces as shown in Fig. 3. To run the algorithms of the model, computer software was elaborated.

3. Modelling results, comparison with experiments

As it was described previously, the proposed model was applied for behaviour prediction of fiber concrete with various fibre concentrations. In this case fiber concrete with follow fibre concentration studied: Tabix L=60 mm, d=1 mm, content 139 kg/m^3, Dramix L=30 mm, d=0.54 mm, content 18 kg/m^3, Straight L=13 mm, d=0.16 mm, content 33 kg/m^3, Straight L=6 mm, d=0.16 mm, content 33 kg/m^3.

To evaluate the validity of the proposed model, parallel experimental testing was performed according to the same loading conditions as for modelling. Fig. 4 represents modelling results also being compared with the experimental data.

Fig. 5 represents the approximation result of proposed model. Till the formation of the crack work only concrete of the beam, therefore the first zone of function of the beam stiffness is straight line. In this zone the material is elastic and general parameter is modulus of elasticity E, what is equal 20GPa. After the formation of the crack the tensile load is still transferred through the crack by the fibres (the bridging effect). Because the fibres are being pulled out of the concrete matrix the ability of the fiber concrete beam to carry the applied load in the post-cracking state purely depends on the capacity of fibres in broken crossection to carry pull-out loads. According to the pull-out curves, were obtained, it follows that only for very small values of δ fibre resistance is increasing, and after reaching the maximal value (see. Fig.1.), fibre resistance to withstand pull-out loads starts to decrease and thus decreases the load bearing capacity of the whole beam's broken crossection.

Beams bending technical theory can be used for determination of beam displacements.

$$EJ\frac{\partial^2 y}{\partial x^2} = A\frac{\partial^2 y}{\partial x^2} = M$$

where y – beam displacement;
$A=EJ$ – stiffness of beam;
Function of the fiber concrete beam stiffness in the first stage (beam without crack) for $\delta \le 0.8$ mm is:

$$A = E\delta$$

After the formation of the crack for function of the fiber concrete beam stiffness was used polynomial approximation in the form:

$$A = a_0 + a_1\delta + a_2\delta^2 = 10.7 + 3.4\delta - 0.4\delta^2$$

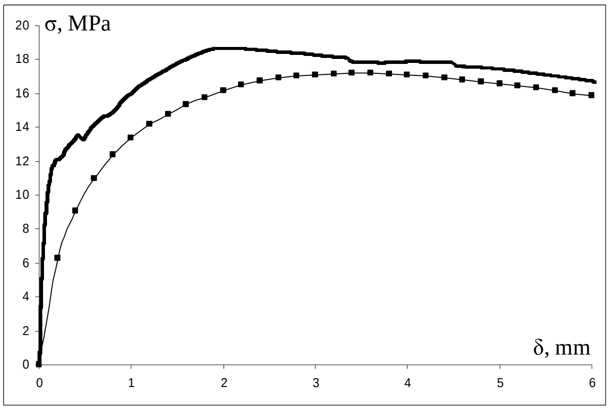

Fig. 4. Function of the fiber concrete beam stiffness ▬▬▬ - experimental curve, —■—■— - theoretical curve

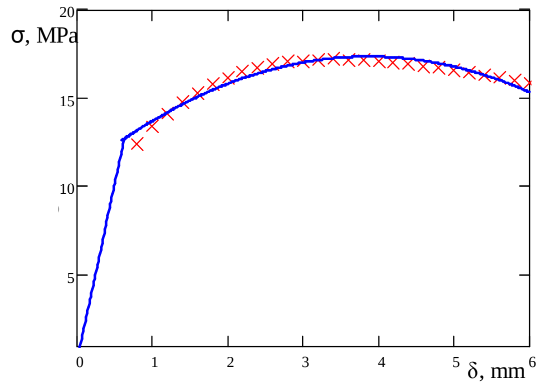

Fig. 5. Approximation of function of the fiber concrete beam stiffness

4. Conclusions

1. Proposed post-cracking behaviour prediction method proved to be in a good agreement with the average experimentally obtained fiber concrete beam bending test results.
2. Good agreement to the experimental results confirms that the main non-linear micro-mechanisms have been successfully comprehended and evaluated.
3. Approximation of function of the fiber concrete beam stiffness was obtained.

5. References

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