ASPECTS OF FLEXURAL BEHAVIOR OF HIGH STRENGTH CONCRETE ELEMENTS WITH OR WITHOUT STEEL FIBERS

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Abstract. Steel fiber reinforced high strength concrete (SFRHSC) is concrete made of hydraulic cements containing fine or fine and coarse aggregate and discontinuous discrete steel fibers. In tension, SFRHSC fails only after the steel fiber breaks or is pulled out of the cement matrix. A more general and current approach to the mechanics of fiber reinforcing assumes a crack arrest mechanism based on fracture mechanics. In this model, the energy to extend a crack and debond the fibers in the matrix relates to the properties of the composite. The designers may best view SFRHSC as a concrete with increased strain capacity, impact resistance, energy absorption, fatigue endurance and tensile strength.

Key words: Steel Fiber Reinforced High Strength Concrete, Bending, Design.

1. Introduction

Steel fibers reinforced high-strength concrete (SFRHSC) is realized of hydraulic cement, career crushed aggregate, mineral admixtures (silica fume), additives (superplasticizers), dispersed steel fiber and water (Magureanu, 2009). Under the action of various loads SFRHSC fails only when steel fibers are broken or pulled out of the concrete matrix (cement + aggregate). Figure 1 shows the variation law and breaking surface of an item tested at bending (ACI Committee 363, 1984).

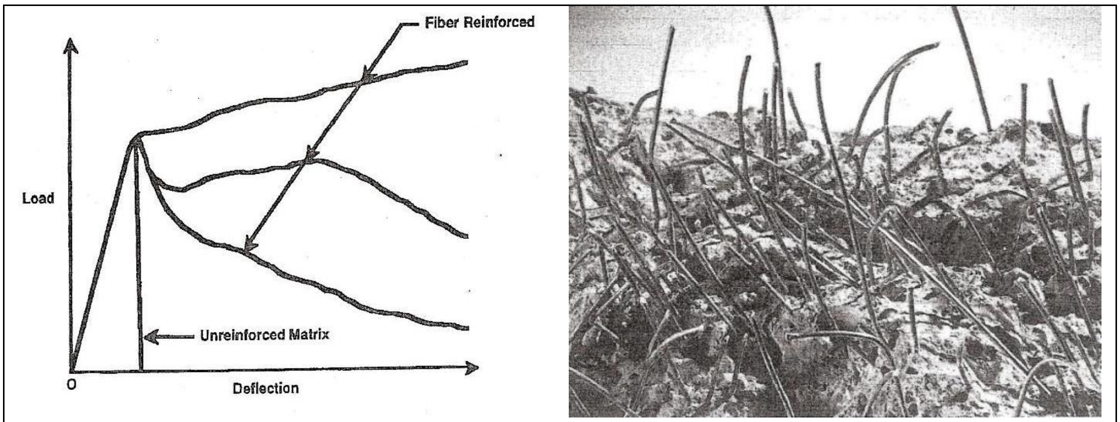

Fig. 1. Failure mode and fracture surface of an element made of SFRHSC

Application of SFRC since the mid-1960s have included road and floor slabs, refractory materials and concrete products. The first commercial SFRC pavement in the United States was placed in August 1971 as a truck weighing station near Ashland, Ohio (Hoff, 1986).

There are some applications where steel fibers have been used without reinforcing bars to carry loads. These have been short span, elevated slabs, for example, a parking garage at Heathrow Airport with slabs 1.07 m square by 10 cm thick, supported on four sides (Carter, 1971).

Till now it were made various approaches to design SFRHSC elements. These are based on conventional design methods, generally supplemented by the contribution of fiber. Additional information regarding the design of these elements can be found in ACI 544.4R "Design Considerations for fiber reinforced concrete" (ACI Committee 544, 1982). In this case, for application of conventional design method (ACI Committee 544, 1982), it was monitoring the influence of high – strength concrete on the dimensioning parameters of concrete sections.

2. Design consideration

Sizing simply reinforced concrete sections in the ultimate limit state at bending moment as required Eurocode 2 (Comité Européen de normalisation, 2006), is done by applying different equations of equilibrium in the most loaded section.

In case of steel fiber reinforced beams, the designing was made using different methods developed by Technological Institute of New Jersey, and used after that by ACI Codes (ACI Committee 544, 1982).

In order to determine the ultimate bending moment capacity for beam FT 5.1-1 (without fibers), the provisions of Eurocode 2 (Comité Européen de normalisation, 2006) were used, adopting the following scheme of efforts distribution in the section (as shown in Fig. 2):

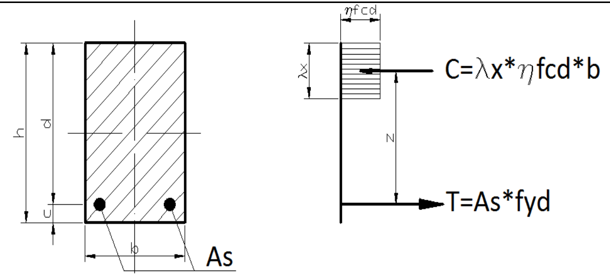

Fig. 2. Effort distribution in the beam section for beam FT5.1-1 in ULS

The bending capacity of the beam FT5.1-1 (without fibers) was calculated according to Equation (2):

$$M_{Eds} = \mu_{\lim} b d^2 \quad (1)$$

$$\mu_{\lim} = \lambda \eta \xi_{\lim} (1 - 0.5 \lambda \xi_{\lim})$$

$$\lambda = 0.8 - \frac{f_{ck} - 50}{400}, \text{ for } f_{ck} > \text{C50/60} \quad (2)$$

where: $\mu_{\lim}$ - coefficient depending on concrete strength, b – section width, d – useful height of section, f_{ck} - design strength of concrete, λ – reduction coefficient of compressed area, η – reduction coefficient of compressive strength.

Equation (1) represents the reduction of compressed area for high-strength concrete. Relation (2) represent the reduce of compression strength in the extreme compression fiber for high strength concretes.

Flexural strength of beams with steel fibers (ACI Committee 544, 1982), is calculated according to the tensile strength of concrete but especially to the contribution assumed by fibers, namely by the fibers volume and by the aspect ratio l/d (fiber length/fiber diameter). Below are the relationships account:

$$\sigma_{cf} = 0.843 f_r V_m + 425 V_f l / d_f \quad (3)$$

where: σ_{cf} - tensile effort, f_r – ultimate strength of compressed concrete, V_m – matrix volume = 1 - V_f, V_f – fibers volume = 1- V_m, l/d_f – aspect ratio (fiber length / fiber diameter).
For the last resistance of the composite next relationship is used:

$$\sigma_{cu} = 0.97 f_r V_m + 494 V_f l / d_f \quad (4)$$

where σ_{cu} is the ultimate effort.

The ultimate bending moment for beam FT 5.2-1 was determined using a calculation method developed by ACI Committee 544 (ACI Committee 544, 1982). In order to evaluate the ultimate bending moment for beam FT 5.2-1, it were used the same principles specified by Eurocode 2, for dimensioning in USL, adding the contribution of steel fibers. The stress distribution in section B is shown in Figure 3.

In this approach it was considered the strength in the extreme compressed fiber as limited to 3 mm / m, yielding value of tensioned reinforcing bars. From the equilibrium of forces on the section, it was obtained the bending moment capacity, as:

$$M_n = A_s f_y \left(d - \frac{a}{2} \right) + f_t b \left(h - \frac{a}{\beta_1} \right) \left(\frac{h}{2} + \frac{a}{2\beta_1} - \frac{a}{2} \right) \quad (5)$$

where: A_s – tensioned reinforcing area, f_y – yield strength of steel, d – useful height of section, a – position of neutral axis, f_t – tensile strength of concrete, b – section width, h – section height, β_1 - reduction coefficient of compressive strength.

The coefficient β_1 was considered equal to 0.85 for concretes with strength upper then 55 MPa.

The position of the neutral axis was determined according to rotation (Figure 4) (Mohammad and Mohd, 2011).

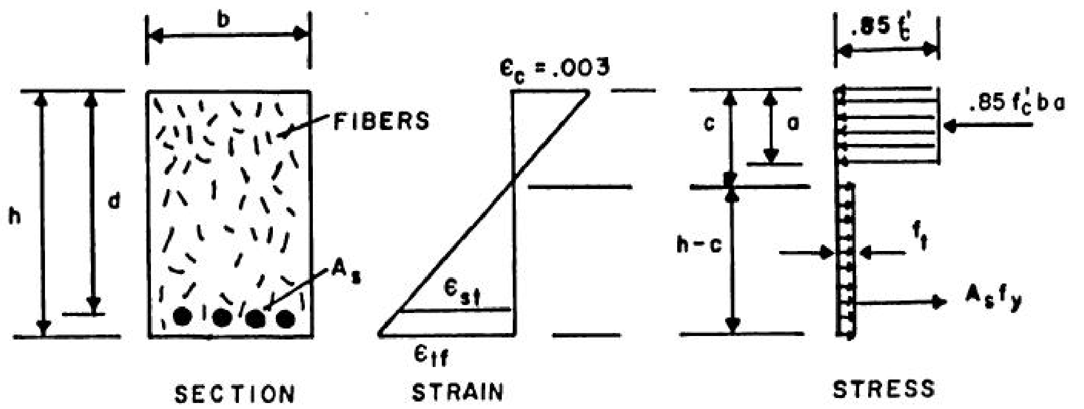

Fig. 3. Effort state in USL for beam FT 5.2-1

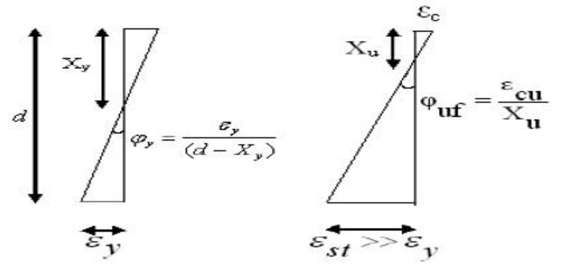

Fig. 4. Section rotation at yielding stress of reinforcement bars φ_y and the ultimate rotation φ_{uf} in section B

Rotation value can be assessed using equation (6) [7] (Mohammad and Mohd, 2011).

$$tag\varphi = \varphi = \frac{\varepsilon_c + \varepsilon_s}{d} \tag{6}$$

According to Figure 4 the neutral axis position can be estimated as (Mohammad and Mohd, 2011).

$$x = \frac{\varepsilon_c}{\varphi} \tag{7}$$

For beam FT5.2-1 with steel fibers, the bending moment M_n can be obtained from the value of the ultimate bending moment:
M_n = 95.15 kNm

The stiffness was estimated as function of the value of the bending moment and the section rotation in the same section and for the same loads, as:

$$EI_{(\exp)} = \frac{M}{\rho} \tag{8}$$

3. Experimental program

The experimental program was performed on two high-strength concrete beams, one with steel fibers (FT 5.2-1) and the second one without fiber (FT 5.1-1). Beam sizes were 130x245x3000 mm.

Concrete properties are shown in Table 1. Geometrical characteristics of fibers were: diameter ¬= 0,40 mm, length l= 25 mm, aspect ratio *l/d* = 0,40/25 (mm) and elastic modulus E_a = 2000 MPa.

The reinforcement scheme of experimental elements is presented in Figure 5.

Longitudinal reinforcement ratio of the beams was ρ_s = 1,60%.

Static scheme was in the form of a simply supported beam with two concentrated forces applied in the middle third (Fig. 6). Load was applied in steps up to the value of 100 kN.

The test setup and instrumentation of the SFRHSC beams are presented in Figure 7. In the experimental program we had the following values: $\lambda = 0.789$, $\eta = 0.978$, $\varepsilon_{cu3} = 3.14$ ‰, $\varepsilon_{yd} = 1.43$ ‰, $\xi_{\lim} = 0.68$, $\mu_{\lim} = 0.38$, $M_{Eds} = 87.81$ kNm.

Table 1. Concrete properties

		Characteristic strength (MPa)	**Design strength (MPa)**	**Elastic modulus E (GPa)**
Concrete	Beam FT 5.1-1	f_{ck} = 54,48	$f_{cd} = \frac{f_{ck}}{\gamma_c} = \frac{54,48}{1,5} = 36,32$	38,00
	Beam FT 5.2-1	f_{ck} = 66,80	$f_{cd} = \frac{f_{ck}}{\gamma_c} = \frac{66,80}{1,5} = 44,54$	40,00

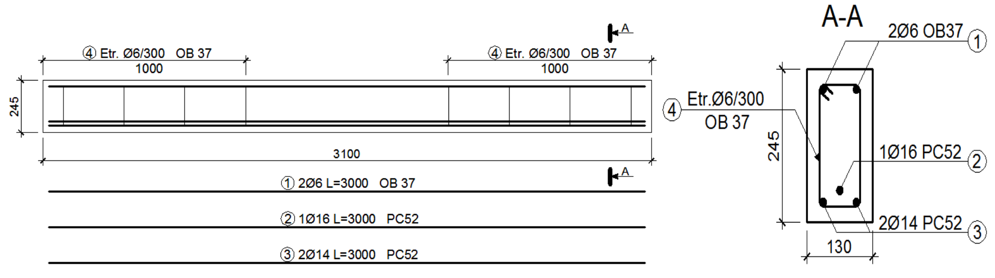

Fig. 5. Reinforcement scheme of the beams

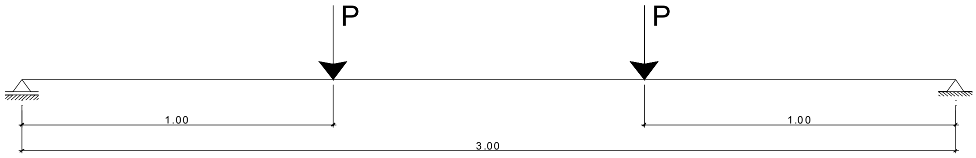

Fig. 6. Static scheme for beams testing

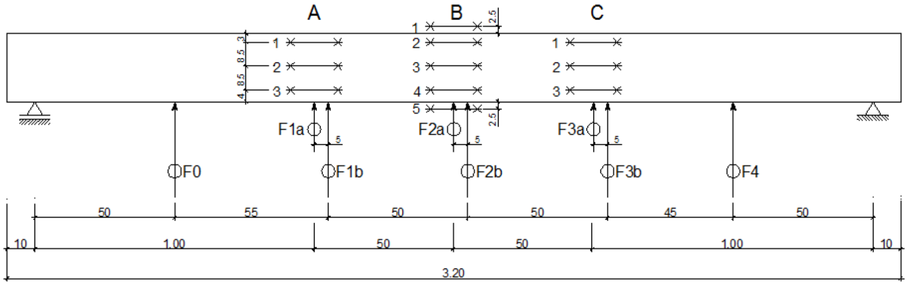

Fig. 7. Fitting mode of the beams

4. Results

Evolution of specific strains was determined in the middle section of the beam and in the most compressed fiber. In the middle zone of the beams, the section rotation, stiffness evolution and depth variation of neutral axis were measured, with load evolution, as shown in Figure 8, Figure 9 and Figure 10.

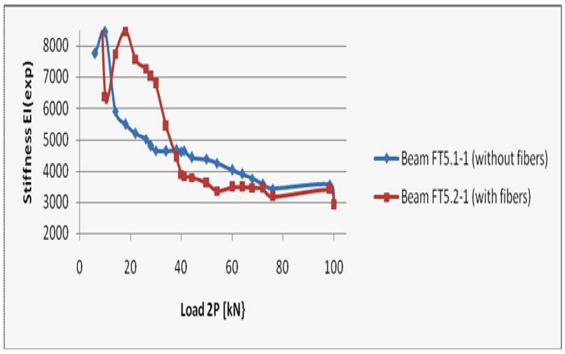

Fig. 9. Stiffness evolution (EI) of the beams

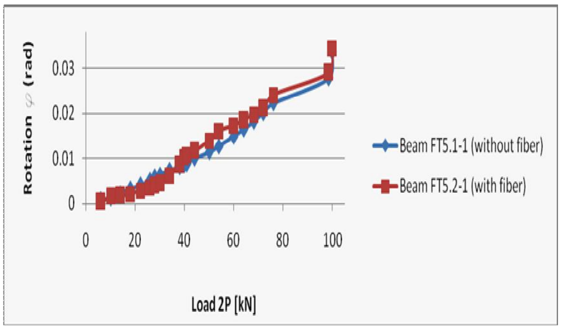

Fig. 8. Section rotation of the beams

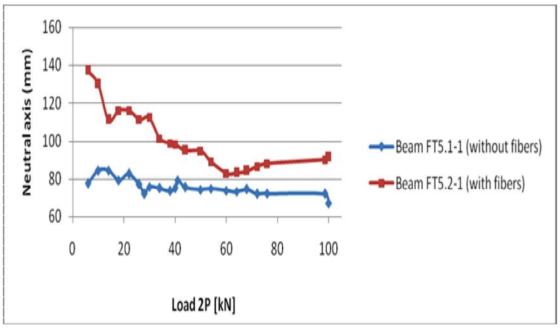

Fig. 10. Variation of the neutral axis

5. Conclusions

The results were obtained by analyzing the central area of the beams, especially in section B. Comparing the evolution of section rotation, it was observed that in case of fiber beam, the value was slightly higher then the value of beam without fibers, phenomenon due to the section ductilization effect realized by fibers.

Regarding the evolution of stiffness (EI) at load increasing, the stiffness of the fiber beam FT 5.2-1 is higher in the first steps of loading, until the cracking of SFRHPC, when the fibers are pulled-out from the concrete matrix.

The position variation of neutral axis at load increasing for beam FT5.2-1 is influenced by the presence of steel fibers. The additional stress necessary for pull out the fibers from the matrix due of the load increasing led to double the high of compressed zone as opposed to beam without fibers.

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