APLICATION OF FIBRE CONCRETE IN SLENDER STRUCTURAL MEMBERS

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Abstract

Contribution shows the efficiency of application of steel fibres in extremely loaded slender structures. A simple example of slender reinforced column tightly fixed in the foundation is considered in the analysis. For such column are calculated and drawn interaction diagrams, which transparently show differences in resistance of fibre concrete and normal strength concrete cross-section. Analysis of structural member is based on the non-linear approach according to requirements of Eurocodes.

Keywords: Fibre concrete, interaction diagram, slenderness

1 Introduction

Fibre concrete undergoes a renaissance in few last years and its usage as a structural material becomes still wider. Interesting could be a comparison of properties of fibre concrete and normal strength concrete (NSC) in slender structures. Contribution follows-up the earlier published paper about reliability of slender structural members in other symposiums [5].

Comparison is illustrated on the interaction diagrams of slender cross-section in relation to material classes, longitudinal reinforcement ratio and slenderness. Analysis of slender structural member is based on the non-linear FE method 1-D, where average material characteristics are applied according to EN1992-1-1 [1], 5.7(4). The negative impact of steel fibres on concrete compressive strength is not considered in presented analysis.

Stress-strain diagrams, which are used in the analysis, come from EN 1992-1-1 [1], MC 90 [2], DBV (Deutscher Beton und Bautechnik Verein) [4] and also from recommendation of RILEM [3]. Unfortunately, there is no standard available, which would give general information about the classification of fibre-concrete. Therefore, adopted classification may be considered as an estimate only.

2 Application of fibre concrete classes in numerical analysis

Design of structural members made of fibre concrete requires a good knowledge of stress-strain diagram. The diagram depends not only on applied concrete mixture, but in tension also on the proportion of steel fibres in unit of the mixture, the material properties of fibres,

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geometry and on interaction between concrete mixture and scattered reinforcement. To create any generally applicable classification is a very difficult task. So far it isn't common, that concreting plants guarantee properties of fibre concrete. For safe and exact structure design of fibre concrete is demanding to know standard deviation in main characteristic of produced mixture, which isn't ordinarily mentioned by producer.

It is used classification according to German handbook of DBV [4] and recommendation of RILEM (TC162-TDF) [3]. Both classifications are based on bending tests. The handbook of DBV [4] estimates strength in tension from conjugated energy *D*. This energy is measured at deflection for serviceability limit state limit (deflection δ=0,65 mm from first crack birth) and for ultimate limit state (deflection δ=3,15 mm from first crack birth). Both deflections are measured in the location of maximal bending moment – in the centre of test specimen. Therefore, the values of stress $f_{\mathrm{eq,ctm,I}}$ and $f_{\mathrm{eq.ctm,II}}$ may be expressed as:

$$f_{\mathrm{eq,ctm,I}} = 1200 \cdot \frac{D_{\mathrm{I}}}{b \cdot d^2}, \quad f_{\mathrm{eq,ctm,II}} = 200 \cdot \frac{D_{\mathrm{II}}}{b \cdot d^2}$$

where *b* is column width and *d* is the effective height of cross-section.

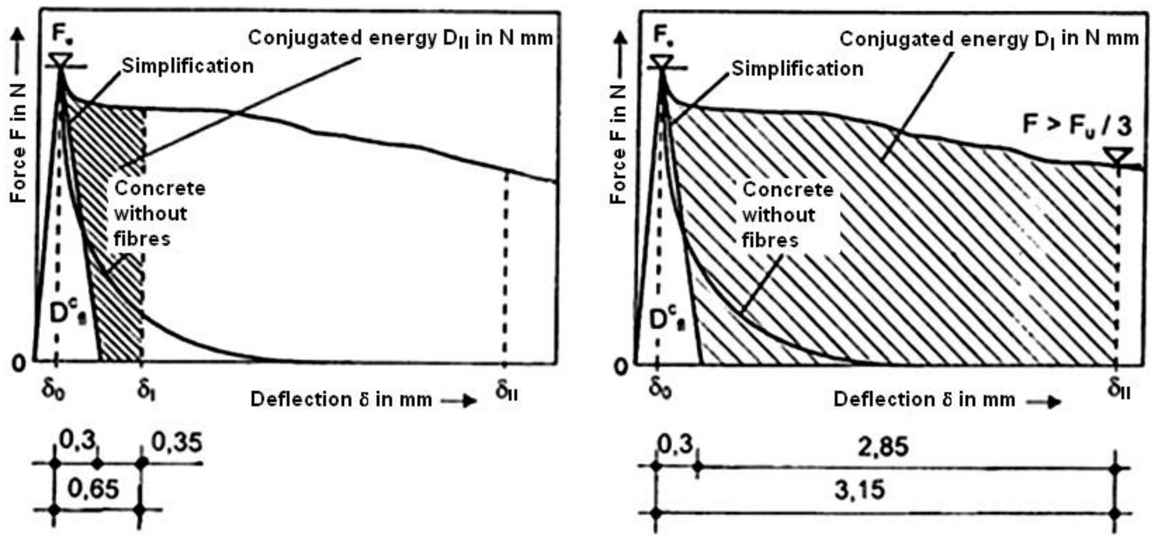

Fig. 1 Stress-strain diagram in tension with displayed conjugated energy for serviceability limit state (on the left) and ultimate limit state (on the right)

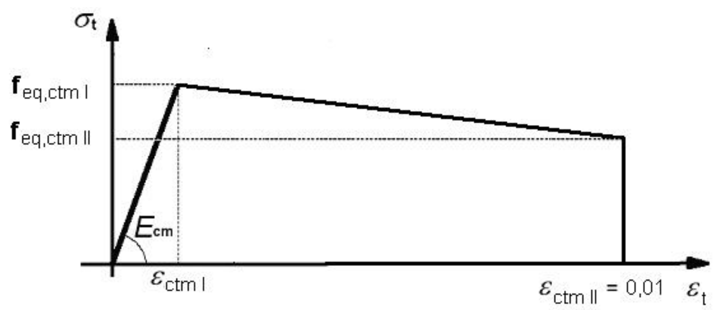

Fig. 2 Stress-strain diagram used for classification according to DBV handbook

Technical committee RILEM [3] in its recommendation gives two types of stress-strain diagrams, from which was chosen here the Method of residual strength. The method is based on residual strength estimated from the specimen deflection of 0,46 mm (loaded by $F_{R,1}$) and 3 mm (loaded by $F_{R,4}$). Relevant characteristics of fibre concrete were determined in the same way as in DBV handbook [4], i.e. from bending tests. Stress-strain diagram includes the size effect in factor κ_h. For fiber length of 6 cm, the strain $\varepsilon_3 = 25‰$ may be considered (for fibres of 3 cm the strain $\varepsilon_3 = 10‰$ would be valid).

$$\sigma_1 = 0{,}7 \cdot f_{\mathrm{ctm,fl}} \cdot (1{,}6 - 0{,}7)\,,\ \ \sigma_2 = 0{,}45 \cdot f_{\mathrm{R},1} \cdot \kappa_\mathrm{h}\,,\ \ \sigma_3 = 0{,}37 \cdot f_{\mathrm{R},4} \cdot \kappa_\mathrm{h}\,,\ \ f_{\mathrm{R,i}} = \frac{3}{2} \cdot \frac{F_{\mathrm{R,i}} \cdot L}{b \cdot h^2}$$

$$\varepsilon_1 = \frac{\sigma_1}{E_{\mathrm{cm}}}\,,\ \ \varepsilon_2 = \varepsilon_1 + 0{,}1‰\,,\ \ \varepsilon_3 = 25‰$$

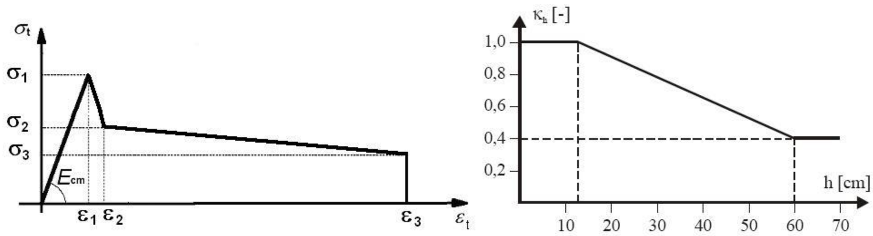

Fig. 3 Stress-strain diagram used for classification according to RILEM recommendation (on the left), dependence of factor κ_h on the cross-section height (on the right)

3 Example: Two different slenderness used in the design of column

Compare a resistance of tightly fixed slender columns (l=6m ~ λ=83,1; l=12m ~ λ=166,3) of the cross-section 0,5 x 0,5 m and different longitudinal reinforcement ratio (σ=0,0064; 0,06). Columns are produced from:

1) Concrete class C25/30 and fibre concrete C25/30 F 1/0,8 and C25/30 F2/2 (according to classification DBV [4]).
2) Concrete class C50/60 and fibre concrete C50/60 (according to evaluated destructive tests carried out by technical committee RILEM (TC162-TDF) [3]).

The reinforcement of class B 500 A is used. Please carry out analysis with average characteristics of materials. The above introduced stress-strain diagrams are considered.

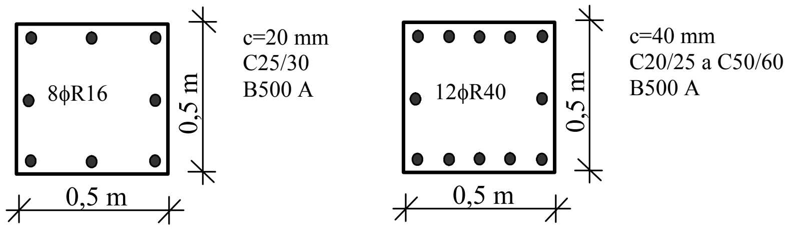

Fig. 4 Column cross-section with reinforcement ratio ρ=0,0064 (on the left side) and ρ=0,06 (on the right side)

4 Solution

The columns were analysed with the help of non-linear FE method 1-D. The stiffness of the structural member was assumed as non-linear, varying with curvature of the cross section. Slender cross section was analyzed in program Mathcad by numerical integration. Compiled program enabled step loading of the member and further specified the action at failure state. Therefore, it was possible to determine the exact ultimate limit state for different ratio of axial force and bending moment. In consequence, the interaction diagram of slender cross-section was build up by connecting of points, which represented the load-bearing capacity.

Stress-strain diagram in compression is adopted from EN 1992-1-1 [1], the tension part without scattered reinforcement is assumed according to CEB-FIP MC90 [2]. Considered stress-strain diagram is shown in Figure 5.

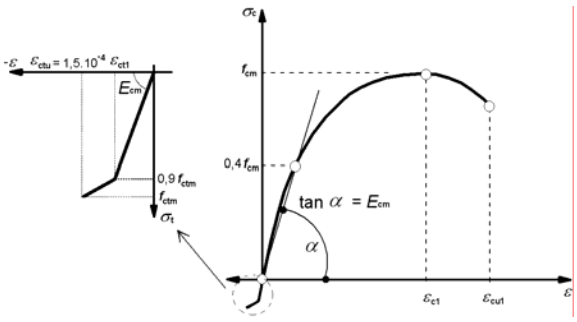

Fig. 5 Used stress-strain diagram of normal strength concrete

4.1 Comparison of normal concrete and fibre concrete according to DBV

The concrete class C25/30 and fibre concrete C25/30 F 1/0,8 and C25/30 F 2/2 were used in a comparative study case. The first number behind F provides the value of stress $f_{eq,ctm,I}$, the second one gives the value of stress $f_{eq.ctm,II}$, see Fig. 2.

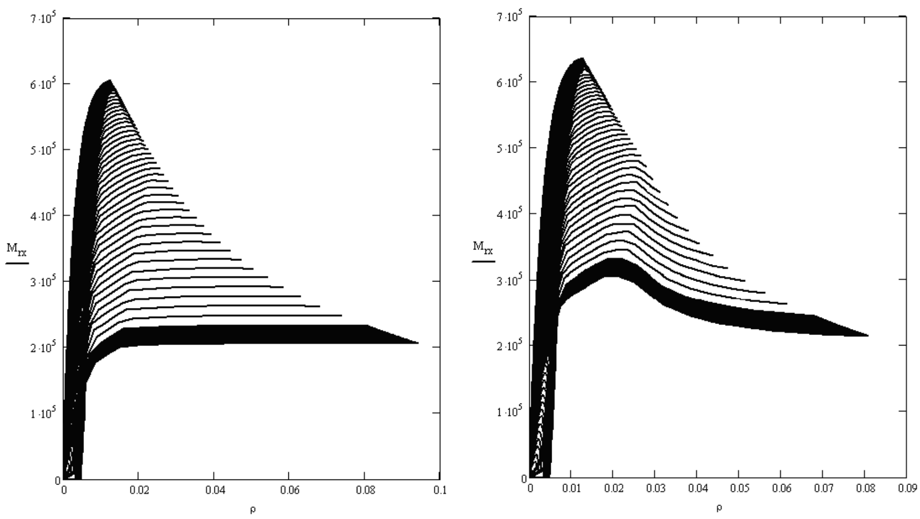

Fig. 6 Comparison of course of curvature versus bending moment: on the left normal strength concrete C25/30, on the right fibre reinforced concrete C25/30 F2/2

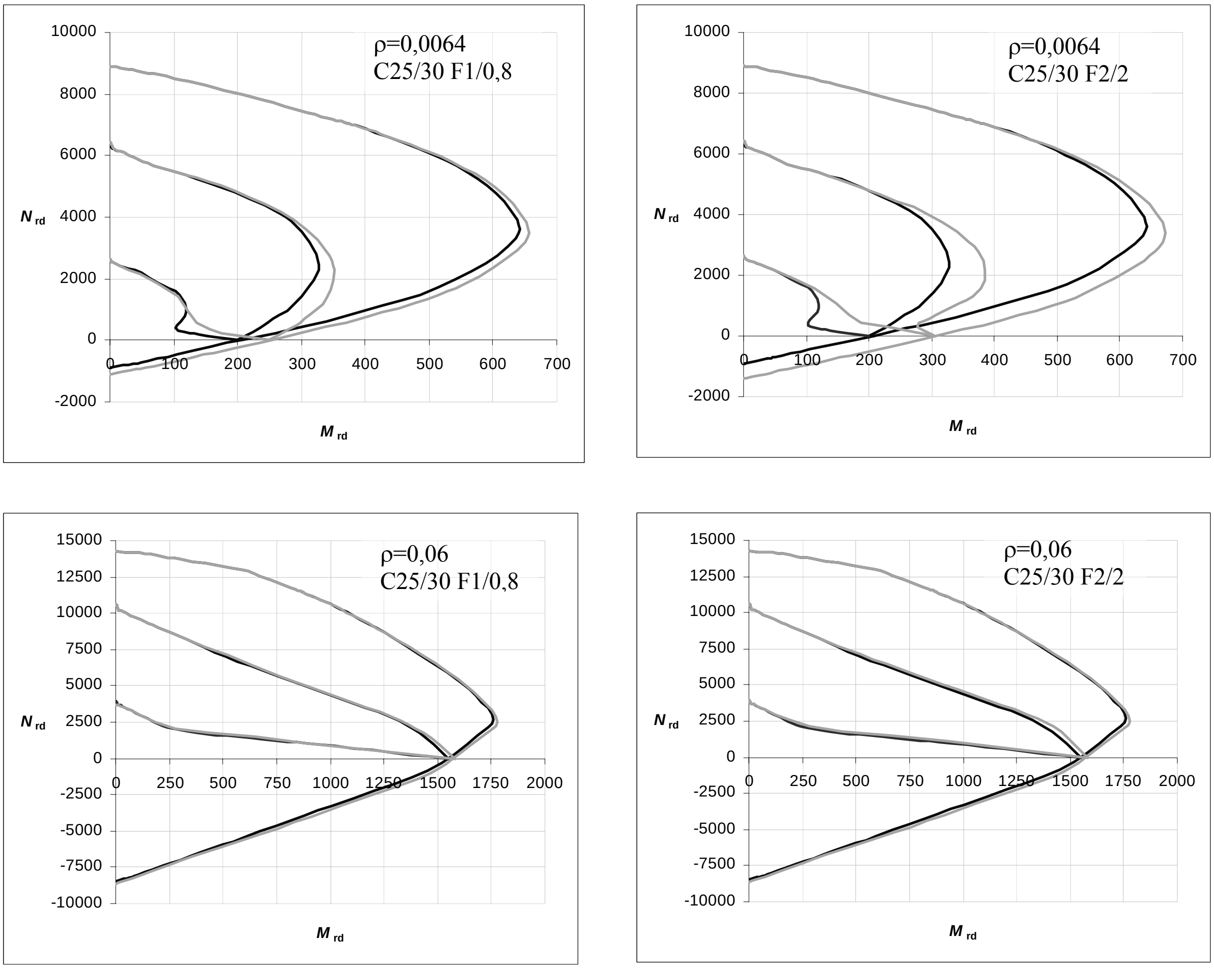

Fig. 7 Comparison of interaction diagrams (N_{rd} in kN, M_{rd} in kNm). The bearing capacity of cross section at different height of 0 m, 6 m and 12m. Black line shows normal strength concrete, grey line shows fibre concrete (DBV). Upper figures have lower reinforcement ratio as bottom ones.

4.2 Comparison of normal concrete and fibre concrete according to RILEM

For comparison it was used concrete class C50/60 and fibre concrete C50/60 - properties in tension are obtained from bending tests [3].

$f_{\mathrm{R,1}} = 5{,}21$ MPa, $f_{\mathrm{R,1}} = 4{,}3$ MPa, $f_{\mathrm{ctm,fl}} = 6{,}8$ MPa (value corresponding to class C/50/60)

$$\sigma_1 = 0{,}7 \cdot f_{\mathrm{ctm,fl}} \cdot (1{,}6 - 0{,}7) = 5{,}3\,\mathrm{MPa} \qquad \varepsilon_1 = \frac{\sigma_1}{E_{\mathrm{cm}}} = \text{variable according to curvature}$$

$$\sigma_2 = 0{,}45 \cdot f_{\mathrm{R,1}} \cdot \kappa_{\mathrm{h}} = 1{,}24\,\mathrm{MPa} \qquad \varepsilon_2 = \varepsilon_1 + 0{,}1‰$$

$$\sigma_3 = 0{,}37 \cdot f_{\mathrm{R,4}} \cdot \kappa_{\mathrm{h}} = 0{,}84\,\mathrm{MPa} \qquad \varepsilon_3 = 25‰$$

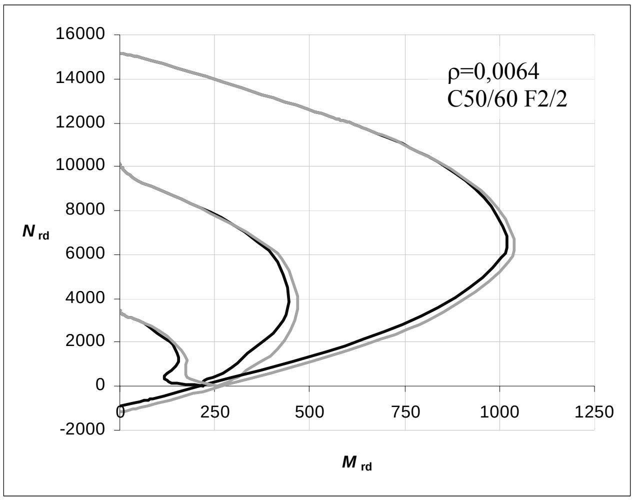

Fig. 7 Comparison of interaction diagrams (N_{rd} in kN, M_{rd} in kNm). Black line shows normal strength concrete, grey line shows fibre concrete (RILEM)

5 Conclusions

It is shown from comparison of interaction diagrams, that the application of fibre reinforced concrete is favourable. Effect of fibres is more obvious on structural members, which are strongly bended. Advantage of the fibre concrete is more visible for lower class concrete mixture with lower longitudinal reinforcement ratio (as illustrated in figures). Obtained results show even 15 % increase of the bearing capacity (if the higher fibre concrete class is applied).

In spite of the fact, that the application of fibre reinforced concrete is from economic reasons inconvenient, in some aspect its behavior is favourable (e.g. durability aspect, resistance again fatigue, cracking width, fire resistance).

Aknowledgements

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References

[1] EN 1992-1-1: *Design of concrete structures – General rules and rules for building*, CEN, 2004

[2] Fédération internationale du béton (fib): *Textbook on Structural Concrete*, Lausanne, 2000

[3] Recommendations of RILEM TC162-TDF: *Test and Design Methods for Steel Fibre Reinforced Concrete: bending test, Materials and Structures*, Vol.33, 2000

[4] Deutscher Beton und Bautechnik Verein: *Ergänzung zur DBV Merkblatt Sammlung: Stahlfaserbeton*, Berlin, 2001

[5] Marek P.: *Nonlinear behavior of slender reinforced structural members*, 5. International Conference on AED, Prague, 11-14.6. 2006