DESIGN OF FIBER REINFORCED CONCRETE STRUCTURAL ELEMENTS

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Introduction

Some aspects of design considering intact and cracked behavior of fiber reinforced concrete elements without bar reinforcement (plain FC elements) are discussed in this paper. Ultimate state (ULS) of the first macro-cracking is the limit of quasi-linear and quasi-plastic behavior of FRC. The ultimate strains of FRC in post-cracking stage, residual and equivalents tensile strength and also ultimate deflections of plain FRC structural elements are preferably studied at ULS and ultimate state of bearing capacity. The design of plain FRC using appropriate material properties should be compatible with standard design of structural members of plain concrete.

FRC is here considered as a composite with concrete matrix and steel fibers. It the contrary to the plain concrete FRC is capable to demonstrate ductility and increase the bearing capacity of the elements. For designers it is of great importance to know exact conditions of the material used. It is interesting that there are standards and recommendations for complicated situations, such as fire defense, flooding, moistening, etc., of FRC, but for FRC itself the unified information on, say, assessment of the material properties, experiment conduction, is poor, so that the assessment of such structural element is restricted to decisions of individuals. The authors of this paper take part in preparation of Technical conditions for testing and design of structural elements from plain FRC, FRC with rebars and FRC with prestressing. Some recommendations follow hereinafter.

Experimental

In this section results from tests and their approximations convenient for computation in the models with overall properties are presented. In Fig. 1 typical stress-strain diagram is seen with elastic-plastic behavior in compressive part and with drop of function after the peak value is attained. In Fig. 2 characteristic distribution of stresses in tensile part is shown from four point test on a beam of $b = h = 150$ mm (width and thickness) and the span is 600 mm. The dashed line is an average from three samples and the thick line describes the characteristic values. Fig. 3 illustrates quasi-plastic approximation in critical cracked section. Fig. 4 is a consequence of evaluation of the previous cases and is considered as computational model in possible numerical models to be shown in what follows. It is worth noting that the model described in Fig. 4 is suitable for beams. Similar tests are carried out for arches.

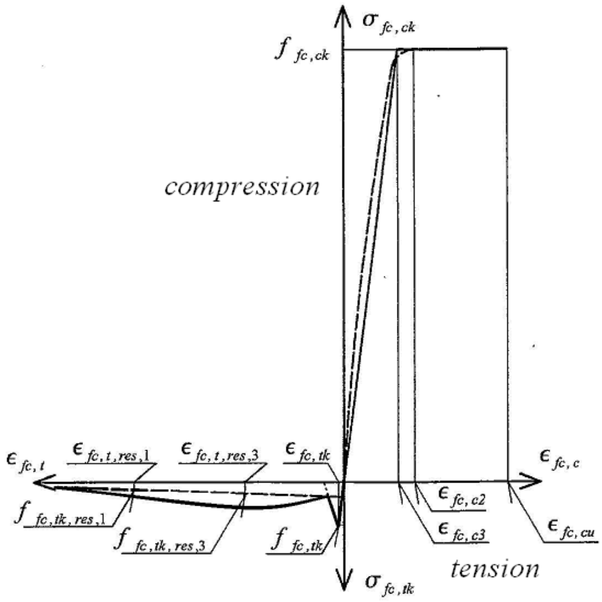

Fig. 1 Characteristic stress-strain diagram and its simplification

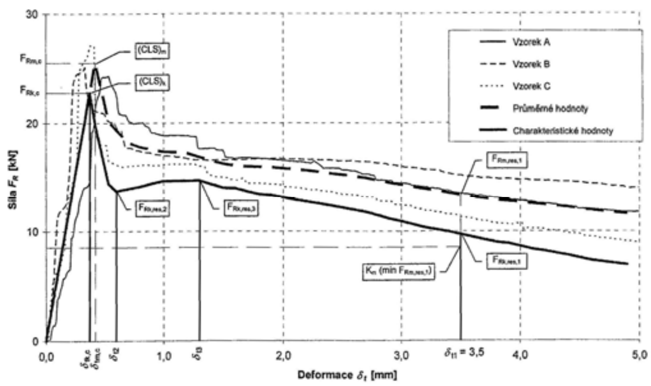

Fig. 2 Mean and characteristic (FR – δ_t)m and (FR – δ_t)k diagrams obtained by bending tests of standard beams ($\delta_{V,f}$ = 0,5%)

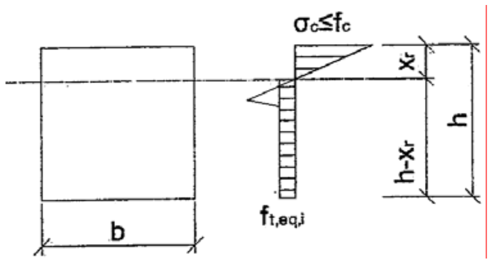

Fig. 3 Stress distribution in standard beam specimen: cracked critical section, quasi-plastic behavior

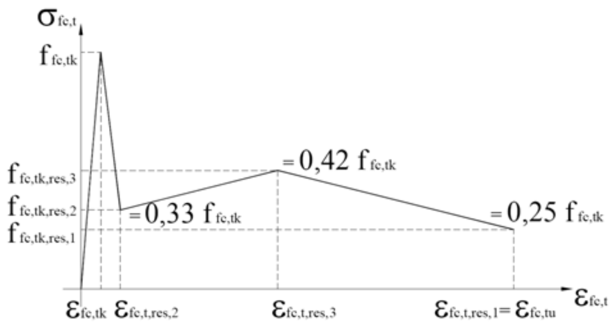

Fig. 4 Tensile part of characteristic stress-strain diagram of FRC with multi-linear distribution

Numerical analysis

Generalized Mohr-Coulomb elasto-plasticity will serve a description of the nonlinear behavior of the system. Let us start with an assumption that at each point of the domain the distribution of effective stresses is known, so that the principal stresses $\sigma_{\max}, \sigma_{\min}$ are known from the previous computation. Moreover, the angle of internal friction φ and the cohesion (shear strength) c are given for elastic, peak and residual states. The latter is respectively denoted by indices e, p, and r. Also the tensile strength σ_+ is given. Denoting $s = \dfrac{\sigma_{\max} + \sigma_{\min}}{2}, r = \dfrac{\sigma_{\max} - \sigma_{\min}}{2}$, according to the previous pictures (particularly Fig. 4) one gets:

- if $\sigma_{\max} \geq \sigma_+$ then the tensile strength is stepped over: $E \approx 0$ (note that in the iteration procedure Young's modulus is set to a small number different from zero)
- if $r \geq r_{\mathrm{p}} = c_{\mathrm{p}} * \cos(\varphi_{\mathrm{p}}) - s * \sin(\varphi_{\mathrm{p}})$ then the peak value is met and Young's modulus becomes E_r and Poisson's number is ν_r.
- if $r \geq r_{\mathrm{e}} = c_{\mathrm{e}} * \cos(\varphi_{\mathrm{e}}) - s * \sin(\varphi_{\mathrm{e}})$ then the elastic boundary (yield function) is met and Young's modulus E_{p}, Poisson's number is ν_r.
- elastic state is considered otherwise.

The situation can graphically be described in Fig. 5. It is worth noting that the plastic part of the scheme can be improved by introducing bi- or tri-linear approximation to fit the graphs in Fig. 2 in a better way.

In the above describe approach the residual area is considered with constant values of material coefficients. Bi-linear behavior as of Fig. 4 can be easily taken into account contemplating linearly increasing distribution in the first part of the residual area and linearly decreasing in the final stage of bearing capacity of the composite envisaged.

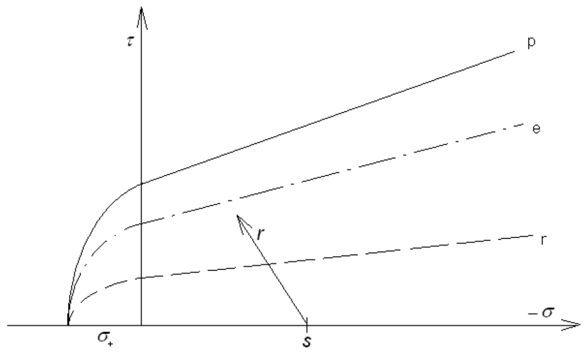

Fig. 5 Mohr-Coulomb envelopes at various states

Conclusion

In this extended abstract certain results from experiments and their approximation for next use are presented. A numerical model has been suggested involving both deformation and incremental methods of plasticity and damage. This approach has been applied in [1] in connection with impact of extreme temperatures. It appears that the results from tests and numerical treatments are in a good agreement. This goal can be attained under condition that the input data are reachable from accessible laboratory tests. Such a condition is fully fulfilled, as the information needed for numerical models can be obtained form standard beams. Moreover, the tests the results from which the pictures are presented here are in compliance with the appropriate Eurocodes and [2], which is recognized as a recommendation in the Czech Republic.

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References

[1] Peskova, S. & Prochazka, P. Impact of high temperature against structures of tunnel lining. CTU Reports 2009, 145 pp., CTU Publ. House, Prague, Czech Republic.

[2] Research group of the department of concrete structures at CTU Prague. Technological conditions of testing FRC (in Czech).