Experimental and numerical investigation of cracking in steel fibre reinforced high performance concrete members

I. Marzec[1*], J. Suchorzewski[1,2], J. Bobiński[1]

[1] Faculty of Civil and Environmental Engineering, Gdańsk University of Technology, Gabriela Narutowicza Street 11/12, 80-233 Gdansk, Poland, ireneusz.marzec@pg.edu.pl
[2] Department of Infrastructure and Concrete Technology, Material Design, RISE Research Institutes of Sweden, Brinellgatan 4, 504 62 Borås, Sweden

High performance concrete (HPC) is a quite novel material which has been rapidly developed in the last few decades. It exhibits superior mechanical properties and durability comparing to normal concrete. HPC can achieve also superior tensile performance if strong fibres (steel or carbon) are implemented in the matrix.

The motivation for this study is a new material design for wave energy convertor (WEC) floater hull, which requires exceptional performance in harsh marine environment under extreme weather conditions over the course of the service-life of minimum 25 years [1]. Fibre reinforced concrete (FRC) utilises its highest performance after initial cracking, exhibiting strain-hardening when the cracks bridged by fibres redistribute the stresses over larger volume of concrete and thus increases the load bearing capacity of the element. The post-cracking behaviour depends greatly on the fibres content, type, geometry, strength and stiffness, as well as the bond between the fibres and the concrete material. Moreover, fibres orientation in the concrete volume is of importance and it usually makes FRC an anisotropic material dependent on the casting direction, what is especially important in thin-walled elements, where the element geometry forces fibres alignment in one direction.

To be able to understand the influence of the fibres content and bond behaviour (dependent also on shape) on the overall behaviour of FRC, numerical models can be used. Such simulation tools are currently under intensive development along with the definition of new concrete mixtures and continuous growth of knowledge about its performance. Two main approaches to describe the behaviour of fibre reinforced concrete can be identified. In the first method fibre reinforced concrete is analysed as a homogeneous material, so the presence of fibres is taken into account only indirectly (so called 'continuous type') e.g. [2]. The alternative idea is based on an explicit definition of fibres distribution (so called 'discrete type') e.g. [3]. Several model were defined base on this approach. In these formulations the slip between fibres can be either neglected (perfect bond), explicitly modelled or it can be indirectly taken into account via the modification of the constitutive relations for fibres.

The goal of the paper is to introduce the numerical tool in order to investigate the behaviour FRC members. The idea is to use the Finite Element Analysis and mesoscale modelling approach to determine the properties of FRC. The main concept of presented approach is to assume the fully 3D modelling with taking into account explicitly the distribution and orientation of the steel fibres. Different approaches in order to simulate the interaction between fibres and concrete are investigated: accurate methods with an explicitly defined contact law and a simplified (indirect) ones assuming only modifications of the material description for steel fibres. Alternatively, a homogeneous law with trilinear softening curve is used. As a benchmark, results obtained from experimental campaign on beams and panels made from high-performance concrete with steel fibres of different sizes and dosages are taken. Results of numerical simulations (especially force-displacement curves) are directly compared with experimental outcomes in order to validate and calibrate FE-model.

References

[1] https://www.wechull.se/
[2] X. Liu, Q. Sun, W Song, Y. Bao, Numerical modeling and parametric study of hybrid fiber-rebar reinforced concrete tunnel linings, Engineering Structures 251 (2022) 113565.
[3] J.E. Bolander Jr, S. Saito, Discrete modeling of short-fiber reinforcement in cementitious composites, Advanced Cement Based Materials 6(3-4) (1997) 76-86.