Towards a proper and efficient continuum constitutive laws of plain and reinforced concrete specimens – a short comparative study

J. Bobiński[1*]

[1] Faculty of Civil and Environmental Engineering, Gdańsk University of Technology, Gabriela Narutowicza Street 11/12, 80-233 Gdansk, Poland, jerzy.bobinski@pg.edu.pl

The presence of cracks in concrete causes very serious difficulties in its precise and physically meaningful mathematical description. Within continuum mechanics there are basically two alternative approaches to handle cracks: as continuous smeared localisation zones or as discrete displacement jumps. Although the latter method describes better macro-cracks, in analysis of larger specimens ("engineering practice") smeared based constitutive laws are widely used. Three main group of models can be distinguished. First are formulated within continuum damage mechanics with isotropic or anisotropic damage variable/variables. In the simplest formulations only one damage variable is defined, while more advanced laws use different measures to independently describe selected phenomena. The second group utilises elasto-plasticity with one or more failure criteria. Finally both approaches can be coupled to take into account both the stiffness degradation and the occurrence of permanent strains. Despite a huge number of existing models, several issues are still open, especially when concrete is subjected to multiaxial stress state.

The paper is a further continuation of previous works [1, 2] where different continuum constitutive laws for concrete were examined to check their ability to simulate the behaviour of plain and reinforced concrete specimens. Here three very sophisticated formulations are analysed. First a model proposed by Červenka and Papanikolaou [3] is chosen in which Menetrey-Willam failure surface in compression was coupled with orthotropic smeared crack approach in tension. The second law used here has been proposed by Grassl and his co-workers [4] and it is based on elasto-plasticity defined in the effective stress space followed by continuum damage mechanics. As a third alternative idea a proposal given by Marzec and Tejchman is analysed [5], which is also based on the same idea as in [4]. As a regularization technique two methods are implemented and examined: fracture energy/crack band approach and an non-local integral theory. The first solution has been originally used in the models formulated in [3, 4], while the second idea was utilised in [5] (and also in [1,2]).

The analysis of all constitutive laws is focused on two aspects: the compatibility of obtained numerical results with experimental outcomes (to be proper) and the identification of the essential features responsible to give opportunity to reduce the complexity of the formulations (to be efficient). The performed analyses deal with two dimensional problems. First a thorough "local" (at a material point level) analysis under complex stress state is performed. Then selected benchmarks of plain (e.g. Nooru-Mohamed test) and reinforced concrete specimens (e.g. bending of a RE beam) are executed. Obtained results are analysed and compared with experiments.

References

[1] J. Bobiński, J. Tejchman, Comparison of continuous and discontinuous constitutive models to simulate concrete behaviour under mixed-mode failure conditions, Int J Numer Anal Methods Geomech 40 (2016) 406-435.

[2] I. Marzec, J. Bobiński, Performance of isotropic constitutive laws in simulating failure mechanisms in scaled RC beams, Arch Mech 72 (2020) 193-215.

[3] J. Červenka, V. K. Papanikolaou, Three dimensional combined fracture–plastic material model for concrete, Int J Plast 24 (2008) 2192-2220.

[4] P. Grassl, D. Xenos, U. Nyström, R. Rempling, K. Gylltoft, CPDM2: A damage-plasticity approach to modelling the failure of concrete, Int J Solids Struct 50 (2013) 3805-3816.

[5] I. Marzec, J. Tejchman, Z. Mróz, Numerical analysis of size effect in RC beams scaled along height or length using elasto-plastic-damage model enhanced by non-local softening, Finite Elem Anal Des 157 (2019) 1-20.