Abstract

Punching shear failures of structural concrete members have been the focus of attention of numerous works presented over the last decades. Although various rational approaches have been developed to predict these failures, there is still no unanimity on a theory consistently describing the phenomenon. An influential rational approach relating the punching strength to the deformation capacity of the slab at failure was proposed by Kinnunen and Nylander (1960). The Critical Shear Crack Theory (CSCT), whose first principles were published in 1991 by Muttoni and Schwartz, is among the works that were later developed consistently with the ideas of the approach of Kinunnen and Nylander. The CSCT has been the object of intensive research in the last two decades in view of its validation, improvement and extension. Consisting of four published scientific articles, the present work investigates the consistency of the principles of the theory for application to members without transverse reinforcement and different slenderness (footings and slabs).

An experimental programme on the punching behaviour of footings is presented to better understand the analogies and differences between the behaviour of slender and squat members. The measurements show that, in addition to the rotation of the slab, the shear strains also significantly influence the state of deformations at failure of squat members. A theoretical work is developed by applying the upper bound theorem of limit analysis. It shows the existence of a flexural-shear interaction in compact footings, influencing their strength and defining a smooth transition between pure flexural and punching shear regimes. A comparison between the theoretical and the experimental results shows that strain- and size-effects need to be considered to correctly predict the punching strength of compact footings using limit analysis.

To investigate the transition between limit analysis and the CSCT, as well as how CSCT handles the punching failures of squat members, the theoretical principles of the CSCT are reviewed and discussed. This study shows that, by accounting for both flexural and shear deformations in the kinematics of the critical shear crack, the theory is applicable to both slender and squat members. In addition, a recently proposed power-law failure criterion is justified based on the different potential failure modes of slender and squat members. Furthermore, closed-form solutions for punching shear design of members without transverse reinforcement are analytically derived combining the power-law failure criterion and a simplified load-rotation relationship. These expressions are validated by comparing their results with a wide range of experimental results of slabs and footings.

A mechanical model is eventually developed and presented on the basis of the theoretical principles of the CSCT, allowing for a refined calculation of the failure criterion by integration of the stresses developing along the critical shear crack. This model is applied to the case of slender slabs and validated against experimental results, showing a good agreement. A parametric study based on the refined failure criterion allows a theoretical validation of both analytical failure criteria of the CSCT as well as of its main assumptions. Finally, the preliminary results of the application of the mechanical model to prestressed slabs and footings show that the principles of the CSCT are also valid to study these cases.

Keywords: structural concrete; punching shear strength; experimental programme; mechanical model; limit analysis; Critical Shear Crack Theory (CSCT); failure criterion; footings; slabs; closed-form design expressions.