Abstract

Reinforced concrete flat slabs constitute one of the most common and efficient modern construction methods. The design of such structural system might be governed by a brittle failure in the vicinity of the slab-column connection associated to punching shear. Several accidents in the last decades motivated the development of solutions to enhance the overall structural response of the slab and to prevent a progressive collapse. The arrangement of transverse reinforcement in the critical zone increases both the strength and the deformation capacity of the slab-column connection. Various punching reinforcing systems have been developed in the past based on intuition and testing. Recent advances on the understanding of the punching phenomena lead nowadays to a better approach of the differences in efficiency and to develop new reinforcement products on a more rational basis.

One of the main parameters identified as governing for the performance of this specific reinforcement is the quality of its anchorage and bond, influencing the development of cracks in the shear-critical region. Such characteristic is generally defined through force-slip relationships and is strongly influenced by the local state of stress and strain. Although the activation of reinforcement often takes place within already cracked concrete for many structural members, the conventional approaches supporting code formulations are still almost exclusively based on tests performed on uncracked specimens. Anchorage of reinforcement bars in cracked concrete is relevant to the structural response of the aging reinforced concrete buildings as well as for the new construction. In the coming years, an increased emphasis should be placed on the study of the performance of reinforcing details in such severe conditions, with the aim to improve the knowledge of this rather underrated but critical problematic.

Several experimental works were thus conducted in the frame of this thesis to improve the current knowledge on the role of the anchorage of the transverse reinforcement in punching shear phenomenon. A programme of pull-out tests on actual detailing solutions was performed in cracked conditions similar to those developing in slabs at the vicinity of the columns. The results highlighted significant differences amongst the evaluated types of anchorages, confirming therefore the various levels of performance observed in punching tests. The activation of this specific reinforcement is investigated in this thesis through tests on full-scale slab specimens provided with extended measurements of the force (external load cells) and crack openings (full and partial thickness variation devices). The use of an innovative reinforcing setup allowed to track the concrete and steel contributions in the punching phenomenon, providing the experimental information required to validate the main assumptions of the Critical Shear Crack Theory for the failure mode within the shear-reinforced area.

Observations on straight bars with in-plane cracking supported the development of analytical formulations to evaluate the reduction of performance –in terms of strength and stiffness– for various anchorage details by analogous considerations to the aggregate interlock approaches. The model is validated through a refined numerical method and the main test results available from literature. Such developments can be partially used within the frame of the Critical Shear Crack Theory, which calculates the contribution of the shear reinforcement in the punching strength –for the failure mode of interest– with a physical model of activation for the transverse elements. The latter contains a number of general assumptions –perfect bond and anchorage conditions, simplified crack kinematics– which can be improved and refined on the basis of the experimental results of the present research. Proposals are formulated to take into account in the existing model a more realistic activation of the transverse reinforcement in the slab during punching –by considering the degradation of the force transfer actions due to the presence of flexural cracks– and thus to improve the understanding and the predictions associated to this failure mode.

Keywords:

punching shear, interior slab-column connections, shear reinforcement, Critical Shear Crack Theory, activation model, failure kinematics, bond and anchorage performance, pull-out tests, cracked concrete, serviceability and ultimate limit states conditions, force-slip relationships