Summary

Punching shear of reinforced concrete flat slabs supported on columns is a failure mode in which the slab fractures around the column. This type of failure is sudden and can be catastrophic in nature. Punching shear generally governs the ultimate limit state design of flat slabs and slab bridges.

The Critical Shear Crack Theory (CSCT) developed by Prof. Muttoni can be used to calculate the punching shear strength in axis-symmetrical cases. The main objective of this work was to investigate non-symmetrical cases of punching shear and to extend the CSCT to such cases. The failure criterion proposed by Prof. Muttoni allows estimating the punching shear strength in terms of the slab rotation in the radial direction. A more general model is needed to predict the punching shear strength of slabs with non-symmetrical conditions.

A numerical model was developed, which is based on the finite difference method, to predict the flexural behaviour of flat slabs. It takes into account the non-linear behaviour of concrete and reinforcement steel and can be applied to non-symmetrical cases and complex structures such as flat slabs with different span length in each direction and slab bridges. Moreover, this model satisfactorily predicts the behaviour of slabs with orthogonal reinforcement and general load cases.

A series of punching shear tests on non-symmetrical slabs was carried out to validate an analytical approach which considers the redistribution of shear stresses along the perimeter. This refined approach provides accurate predictions of strength and slab rotations in both orthogonal directions at failure. Moreover, this approach can be a useful tool for the structural assessment of existing structures.

An analytical model is also presented which extends the CSCT to punching shear cases of internal columns with moment transfer, edge columns, and corner columns, which are commonly found in practice. The comparison between the analytical and experimental results shows that the approach developed combined with the failure criterion used in the CSCT provides accurate predictions of strength and deformation capacity for internal columns with moment transfer, edge columns, and corner columns. This work was also used to validate the formulation of the first complete draft of the Model Code 2010.

In this work, the punching shear behaviour of flat slabs with bent-up bars was also investigated. Bent-up bars were commonly used in the past and are still used nowadays

for particular design situations. A reliable model is needed to design structures and to assess existing structures with bent-up bars. To address this, five punching shear tests were performed on symmetrical slabs with bent-up bars. The strain measurements along the reinforcement bars provided a better understanding of the anchorage mechanisms. A model was developed, which is consistent with the CSCT and provides satisfactory predictions of the distribution of strains along the bent-up bar. The proposed model can be used to calculate the contribution of the bent-up bars, which needs to be added to the concrete contribution from the CSCT to obtain the punching shear strength.

Keywords : reinforced concrete, punching shear, non-symmetrical punching shear, eccentric punching shear, slabs, flat slabs, slab bridges, critical shear crack theory, tests, unbalanced moment, shear reinforcement, bent–up reinforcement, non–linear analysis, finite difference method, Model Code 2010.