Summary

Reinforced concrete flat slabs are extensively used in buildings and parking garages. Their design is governed by deflection at the serviceability limit state and punching shear at the ultimate limit state. When no punching shear reinforcement is provided, failure develops in a brittle manner. Punching shear failure occurs with almost no warning signs, because deflections are small and cracks at the top side of the slab are usually not visible.

Over the past decades, several structural collapses occurred due to punching shear failure resulting in human casualties and large damages. These collapses revealed some shortcomings in codes of practice and the necessity of reconsidering punching provisions. The investigations of these collapses showed that the collapse initiated from a local punching failure and propagated throughout the structure, in a progressive collapse. The term progressive collapse refers to the spreading of an initial local failure triggered by the loss of one or more load carrying members and leading to partial or total collapse of the structure in a manner analogous to the chain reaction. As a local punching failure can trigger progressive collapse, the study of the post-punching behavior can help adopting constructive solutions to avoid progressive collapse.

The post-punching behavior of flat slabs supported by columns has not yet been thoroughly investigated. Therefore, an extensive experimental campaign was performed in the framework of this dissertation to investigate the post-punching behavior of 24 slabs with various reinforcement layouts. The effects of bending reinforcement, integrity reinforcement, bent-up bars, steel type, and anchorage conditions on the post-punching behavior of slab-column connections were investigated. The performance and robustness of the various solutions was investigated to obtain physical explanations of the load-carrying mechanisms.

Test results showed that the post-punching strength provided by the top reinforcement is small because the concrete cover is thin and spalling of the concrete cover occurs leaving the reinforcement ineffective. In addition, it was observed that integrity reinforcing bars passing through the column significantly improve the post-punching behavior in terms of strength and deformation capacity. The integrity bars behave as a tensile membrane inclined to the plane of the slab and are able to sustain damaged portions from the column. Thus, one possibility to enhance the robustness of the structure against progressive collapse is to provide well-anchored bottom reinforcing bars passing through the column.

A mechanical model capable of predicting the post-punching behavior of slab-column connections without shear reinforcement was developed. The model predicts the contribution of the tensile reinforcement and of the integrity reinforcement to the post-punching strength. The model accounts for possible failure modes including the fracture of the bars and the destruction of the concrete over the integrity bars. The progressive destruction of the concrete within and outside the punching cone is treated by considering the pullout behavior of reinforcement embedded in the concrete.

Finally, a parametric study was performed to evaluate the influence of various parameters and their relative importance in order to develop practical proposals for the estimation of the post-punching strength. It showed that the post-punching strength is not only a function of the cross sectional area and yield strength of the integrity reinforcement as it appears in provisions and codes of practices but also of the diameter of the bars, the effective depth, the ductility, and the type of reinforcement.

Key words:

Flat slab, slab-column connection, progressive collapse, punching failure, post-punching strength, dowel action, integrity reinforcement, punching cone, robustness, ductility, concrete destruction, spalling of concrete cover