

Abstract

Reinforced concrete flat slabs consist of a continuous, thin concrete plate that rests on a grid of columns. The supporting surface of the columns is very small compared to the floor plan dimensions, leading to concentrations of shear forces near the columns which can trigger a punching failure at the slab-column connection. This failure mode is of brittle nature and risks triggering the progressive collapse of the structure. The first applications of this structural system date from the early 1900s, when various solutions were developed, such as the ones patented by Turner or Maillart. Both identified these concentrations of forces as a critical point that jeopardised the structural integrity of a slab, and provided column capitals to increase the supporting area. Nowadays, punching is commonly fought by introducing transverse steel reinforcement in the slab. In this context, this thesis addresses the enhancement of the resistance of flat slabs at internal and edge columns (at the building perimeter) by conventional transverse (shear) reinforcement or steel fibres.

The first part of the thesis examines the punching resistance of slabs at edge columns, with and without shear reinforcement. The results of a test programme comprising two specimens with moment continuity in the direction of the load eccentricity are presented. Refined measurements were performed to capture the internal cracking of the slab and the activation of the flexural and shear reinforcement. This allowed understanding the process of failure propagation from the column front towards the free edge of the slab. Additionally, the various punching shear transfer actions and their relative contribution to the slab's resistance were quantified.

The second part of the thesis investigates the maximum punching resistance of shear-reinforced slabs at internal columns. Based on the theoretical principles of the Critical Shear Crack Theory, a refined mechanical model is proposed to evaluate the resistance of a connection by integrating the stresses developing along the failure surface (critical shear crack). A simplified analytical model is derived from this refined approach to calculate the maximum punching resistance of shear-reinforced slabs, which can also be used for slabs without shear reinforcement. A law to describe the relationship between the shear force and the shear deformations is proposed, which allows accounting for redistributions of shear forces around the support perimeter, useful for non-axisymmetric punching scenarios.

The third part of the thesis analyses the contribution of fibres to the resistance of a steel fibre reinforced concrete slab as a function of their measured orientation in the concrete volume. The fibre orientation of six slabs tested in punching is evaluated and a

formulation is developed to quantify the relationship between the measured fibre orientation and an isotropic distribution. Effectiveness factors for punching and flexure are derived to assess in a simplified manner the actual contribution of fibres to the flexural response and punching resistance of a slab. The proposed analytical model for punching is used in combination with the Variable Engagement Model to evaluate the contribution of steel fibres to the resistance of the investigated slabs.

Keywords

Punching, flat slab, Critical Shear Crack Theory, edge column, shear reinforcement, maximum punching resistance, refined mechanical model, analytical model, steel fibre reinforcement, fibre orientation.