Punching in flat slabs subjected to cyclic horizontal loading

Summary

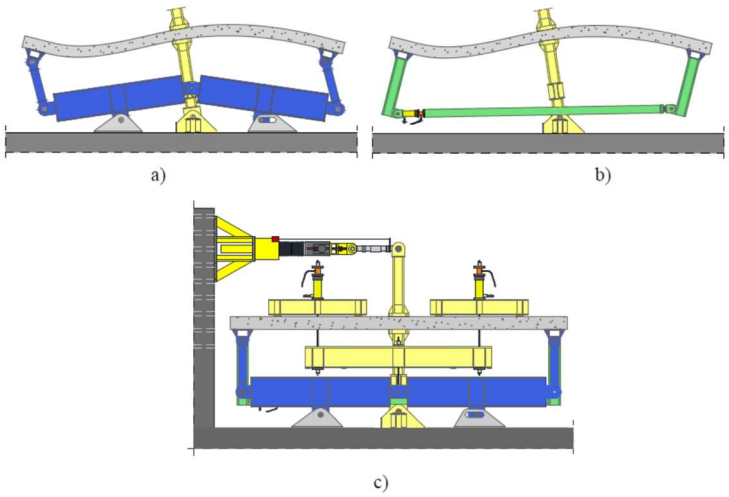
The aim of this work is to study the behaviour of reinforced concrete flat slab structures under combined vertical and horizontal cyclic loading. A total of eleven similar reinforced concrete slabs were cast and tested, measuring 4.25x1.85x0.15m³. The cyclic tests were performed using an innovative test setup that aimed to simulate the boundary conditions of a flat slab, representing the slab between middle spans in one direction and between zero bending moment points in the other direction. It was designed to allow bending moment redistribution, mobility of the line of inflection, assure equal vertical displacements and rotations at the opposite free borders, and, therefore, symmetrical shear forces and equal bending moments, as expected in a real structure.

The slab specimens were connected to two steel half columns, by 0.25x0.25m² rigid steel plates prestressed against the slab using steel bolts, to ensure monolithic behaviour. The slabs were divided in groups, according to the characteristics of the test protocol and the tested variables. A reference specimen was subjected to centred punching, and the results were used to predict the punching capacity of the remaining slabs. One specimen was tested under constant vertical loading and monotonically increased eccentricity until failure. In the cyclic tests, the vertical load was first applied and kept constant during the test, while the cyclic horizontal loading, was increased, in steps of three cycles, until failure. Three specimens were tested under constant vertical load, at different shear ratios, and cyclic increasing horizontal loading. Two slabs were tested using post installed shear bolts arranged in two different solutions, one using a radial distribution around the column and another using a cross distribution.

Four slab specimens with shear reinforcement were tested with different shear reinforcement ratios and number of stirrup layers. Results show that cyclic horizontal actions are very harmful to the slab-column connection, resulting in low horizontal drift, if no adequate shear reinforcement is provided, and low energy dissipation. The post installed steel bolts were proven to be an efficient solution for strengthening existing structures, improving the structural behaviour and the punching resistance. Also, the use of steel stirrups as shear reinforcement is very effective, increasing shear, drift and energy dissipation capacities. Finally, design recommendations and a proposition for the calculation of a minimum shear reinforcement are suggested.

Keywords

Flat slab, reinforced concrete, cyclic, shear ratio, punching stirrups, bolts, shear reinforcement.



Elevation drawing of the test setup at DEC/FCT/UNL for the flat slab horizontal cycling loading tests: a) vertical displacement and shear force compatibilization system under slab's vertical and horizontal deformation; b) rotation and bending moment compatibilization system under slab's vertical and horizontal deformation; and c) complete test setup.

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