FLAT SLAB PUNCHING BEHAVIOUR UNDER CYCLIC HORIZONTAL LOADING

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Abstract

This experimental work aims to study the behaviour of reinforced concrete flat slabs, without shear reinforcement, under gravity and horizontal loading. The effect of gravity load ratio, drift amplitude and horizontal loading nature (cyclic or monotonic) were the studied variables, to ascertain its influence in load and drift capacity, as well as slab-column connection degradation. To accomplish this, four similar flat slab specimens, measuring 4.15x1.85x0.15m^3, were tested under different test protocols, using an innovative test setup whose boundary conditions better approximate laboratory specimens to reality. The obtained results show that cyclic horizontal loads are extremely detrimental to the slab-column connection. The observed drift capacity is not satisfactory, even under low gravity loads.

Keywords: Cyclic Load, Experimental Work, Flat Slab, Punching, Seismic Action

1 Specimens and Materials

Punching failure is a widely studied phenomenon, however, punching under cyclic horizontal loading still is a not well known subject by the scientific community. Because of the phenomenon complexity, the majority of the experimental tests performed to study this subject are simplified representations of slab-column connections that do not represent well the real behaviour. In this experimental work, more realistic boundary conditions were used to ensure a non-zero bending moment at mid-span and consequently a non-fixed null bending moment line, with the following requirements in mind: for gravity load only, shear forces and rotations at the N-S borders were null and the vertical displacements as well as bending moments were equal; when cyclic horizontal loads take place, rotations, vertical displacements and shear forces at the N-S borders should be equal in magnitude; the zero bending moment lines must have mobility. To do so, a combination of two passive systems was used. Two double pinned struts connecting the two borders granted the bending moment and rotation to be similar, while four seesaw like elements took care of the vertical displacements and shear forces equality. All the elements from those systems were designed to be rigid so they do not interfere with the test results.

Both test protocols consisted in applying a gravity load until a specified ratio to be kept constant throughout the test. Then, starting in the N-S direction, a horizontal displacement was induced at the columns top, according to the protocol. The number in the specimens name is the gravity load ratio in percentage of the EC2 provision. The target gravity load was applied by four hydraulic jacks. Table 1 shows each test's main characteristics.

2 Test results

The test setup worked as expected. Vertical displacement increased for cycles under the same drift step and bending cracks appeared at slabs' soffit, at mid-span, showing the presence of positive bending moments in that region. Inflection points were also visible in the slab's deformed shape. No issues were spotted such as column decompression, sliding or concrete crushing underneath. All specimens, presented negative bending moment cracking along the E-W for the target gravity load, although, strain gauges at the top reinforcement rebars show no yielding at that load stage. After gravity load was applied, a horizontal displacement was imposed. The presence of unbalanced bending moment was observed through strain gauges' data. A strain increase at the decompressed side was observed, opposed to a strain decrease at the compressed side resulting in a more prominent cracking at the first side and crack closing at other side of the slab. Top longitudinal reinforcement under the column experienced a stress signal inversion for higher drifts, going into a compression state. This phenomenon was not observed for rebars farther from the column, which indicates that unbalanced moment is absorbed in the column's vicinity, in a relatively short length of the slab. Lower shear ratios widen this length. The hysteretic behaviour depicted in Figure 2 show a low energy dissipation capacity.

EC2's formulation for eccentric punching was applied for all specimens. Results presented in Table 1 shows that the EC2 provisions are fairly accurate, although, non-conservative for the C-50 specimen. This formulation, however, when used with elastic moments, is very conservative, which is not applicable for design purposes. The real unbalanced bending moment calculation is a non-linear complex process and for this reason, it is also difficult to predict the slab's drift capacity. It is important to ensure drift capacity taking advantage of the slab's stiffness loss.

Table 1 – Specimens characteristics and experimental results

Slab	$f_{cm,cube}$ [MPa]	f_{cm} [MPa]	d [mm]	ρ [%]	$V_{Rc,EC2}$ [kN]	β	β V_{exp} [kN]	V_{Rc} /β V_{exp}
E-50	56.7	45.3	117.6	0.96	425.3	2.06	439.2	1.03
C-50	50.3	38.9	118.4	0.96	406.9	1.91	389.3	0.96
C-40	52.7	42.2	118.3	0.96	418.4	2.62	439.3	1.05
C-30	61.2	49.0	117.9	0.96	437.7	3.33	437.2	1.00

Figure 1 – Test setup.

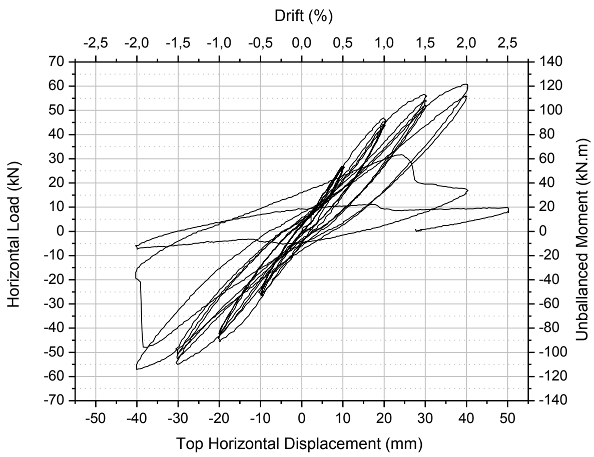

Figure 2 - C-30. Hysteretic diagram.

3 Conclusions

This paper describes the experimental work developed at FCT/UNL to study the behaviour of flat slabs under gravity and horizontal cyclic loads. The main conclusions are: the test setup accomplished all its goals; the achieved drift capacity grows in inverse proportion to the gravity load ratio; no rebars yielded for gravity load only; when horizontal action takes place, rebars under the column are the most stressed. Strain gauges show that the unbalanced moment is absorbed in the column's vicinity, in a relatively short length of the slab. This length widens up for smaller gravity loads. EC2's formulation for eccentric punching predicts satisfactorily the supported unbalanced moment, however, using it to predicting drift capacity is a very complex task.