BEHAVIOUR AND DESIGN OF SLAB-COLUMN JOINTS

Roberto Guidotti   **Miguel Fernández Ruiz**   **Aurelio Muttoni**

Abstract

This paper presents an investigation on the behaviour and strength of slab-column joints in multy-storey buildings. Such joints may develop different potential failure modes such as crushing of the concrete of the slab (due to column loading), bending or punching shear failures (due to slab loading).

The paper presents the results of a test series on 9 full-scale slabs (250 mm thick) loaded to simulate simultaneously column and slab loading. The ratio between the loads was varied from moderate to fairly large column loading. The experimental results confirm a strong interaction between column and slab loads with unexpected increases on the punching shear strength as column loads are larger than the uniaxial compressive strength of the slab. The observed behaviours can be explained on the basis of the theory of plasticity and by using the Critical Shear Crack Theory, leading to a physically-grounded design method for these regions.

Keywords: Punching shear, Multi-storey buildings, Slab-column joints, Crushing of concrete, Critical shear crack theory, Flat slabs, Theory of plasticity

1   Introduction

Flat slabs supported by columns are popular solutions for multy-storey buildings. Columns are typically cast in high strength concrete whereas the slabs are cast in normal strength concrete. In addition, precast columns are usually not continuous through the slabs to enhance easiness of construction (**Fig. 1**). Due to these reasons, slabs have to carry fairly large compressive forces coming from the columns. These loads may potentially be larger than the uniaxial concrete compressive strength of the slab and may lead to crushing the concrete between columns. In addition to column loading, slab-column joints also have to carry shear and bending moments due to the loads applied to the slab, which can lead to flexural or punching shear failures. Consequently, slab-column joints are subjected to a complex stress state, where various potential failure modes can develop and whose interaction has so far not been clearly established.

In practice, many construction details can be used for slab-column joints [1,2]. For instance, for precast columns with low or moderate levels of axial load, the most economical solution is typically to cast the slab without including any connection device between columns (**Fig. 2**). In this research, the authors investigated the behaviour and limits of applicability of such solution with reference to their crushing, punching and bending strength. A detailed summary of the research and its main conclusions can be found in [1,2,4].
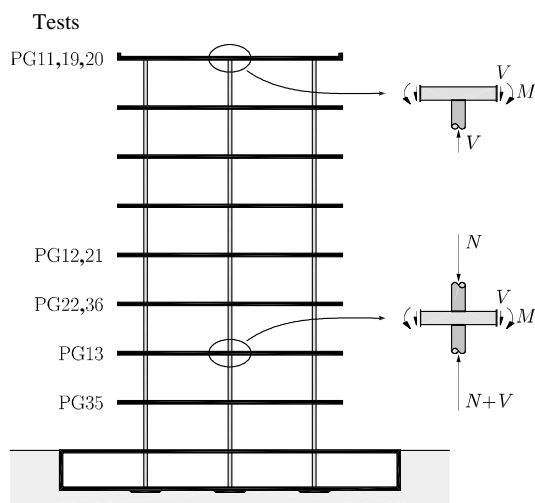
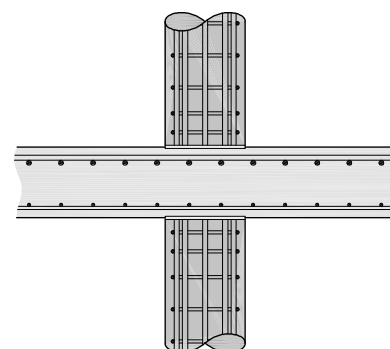**Fig. 1** Flat slab-column joints in a building with varying column load and indication of performed tests

Fig. 2 Column-joint detail with precast columns investigated in this research

2   Experimental programme

An experimental programme was carried out on 9 test specimens 0.25 m thick, see **Fig. 3**. The tests were designed to reproduce actual loading conditions of slab-column joints with precast columns for varying levels of column loading.
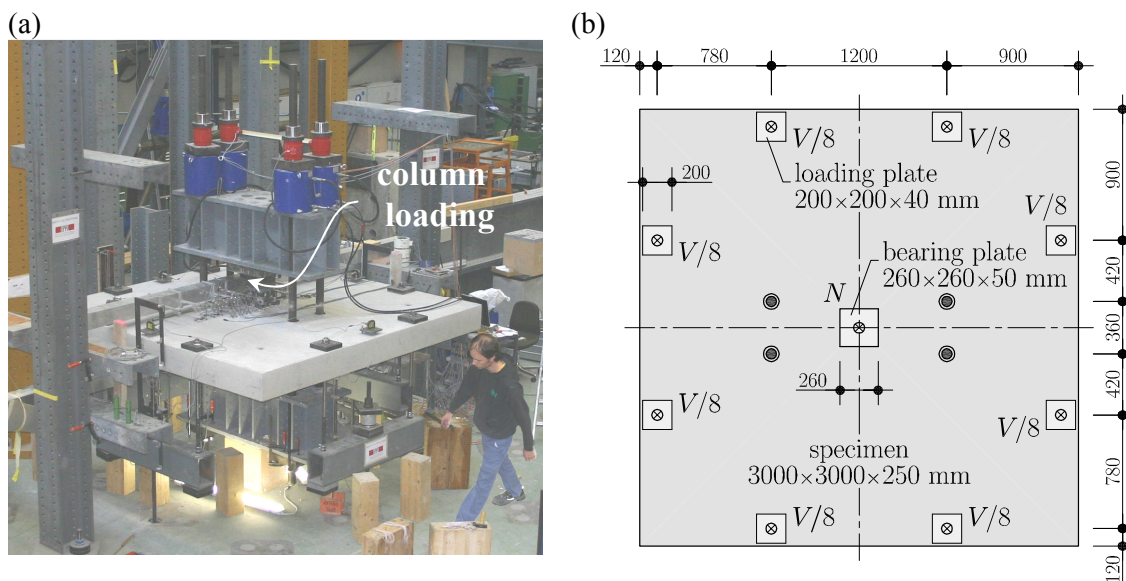

Fig. 3 Experimental programme: (a) view of specimen and test setup; (b) main geometrical dimensions of specimens

Three reference tests were performed without column loading (refer to **Fig. 1**), whereas the other 6 were performed with an applied column load at failure equivalent to 5, 6, 7 or 8 storeys above the specimen (refer to **Fig. 1**). The main mechanical parameters and measured resistances are given in **Tab. 1**. Detailed properties of the specimens and test results can be found in [1].

All specimens were cast in normal strength concrete with compressive strength (measured in cylinder) ranging between 31.5 and 51.7 MPa and with constant aggregate size equal to 16 mm. Two nominal flexural reinforcement ratios (ρ) were selected: 0.75% and 1.50%. The main

experimental results are shown in **Fig. 4** as a function of the applied column load (N), slab load (V) and measured rotations at the column region (ψ).

Tab. 1 Summary of main properties of the specimens and test results (failure loads refer to the column load ($N_{c,R}$) measured when the maximum slab force (V_R) was reached).

| Specimen	f_c [MPa]	ρ [%]	d [mm]	f_y, [MPa]	$V_{R,test}$ [MN]	$N_{R,test}$ [MN]	$N_{R,test}$ /$f_c A_c$	$\psi_{R,test}$ [‰]
PG11	31.5	0.771	208	538	0.763	0	0	10.3
PG12	34.5	0.810	198	538	0.957	3.868	1.66	21.0
PG13	33.9	0.822	195	538	1.027	6.611	2.88	29.9
PG19	46.2	0.781	206	510	0.860	0	0	12.1
PG35	49.6	0.785	205	510	0.894	6.577	1.96	43.5
PG20	51.7	1.563	201	551	1.094	0	0	9.2
PG21	47.3	1.611	195	551	1.105	4.227	1.32	10.3
PG22	48.4	1.571	200	551	1.428	7.275	2.22	17.2
PG36	49.5	1.518	207	551	1.543	8.364	2.50	16.9
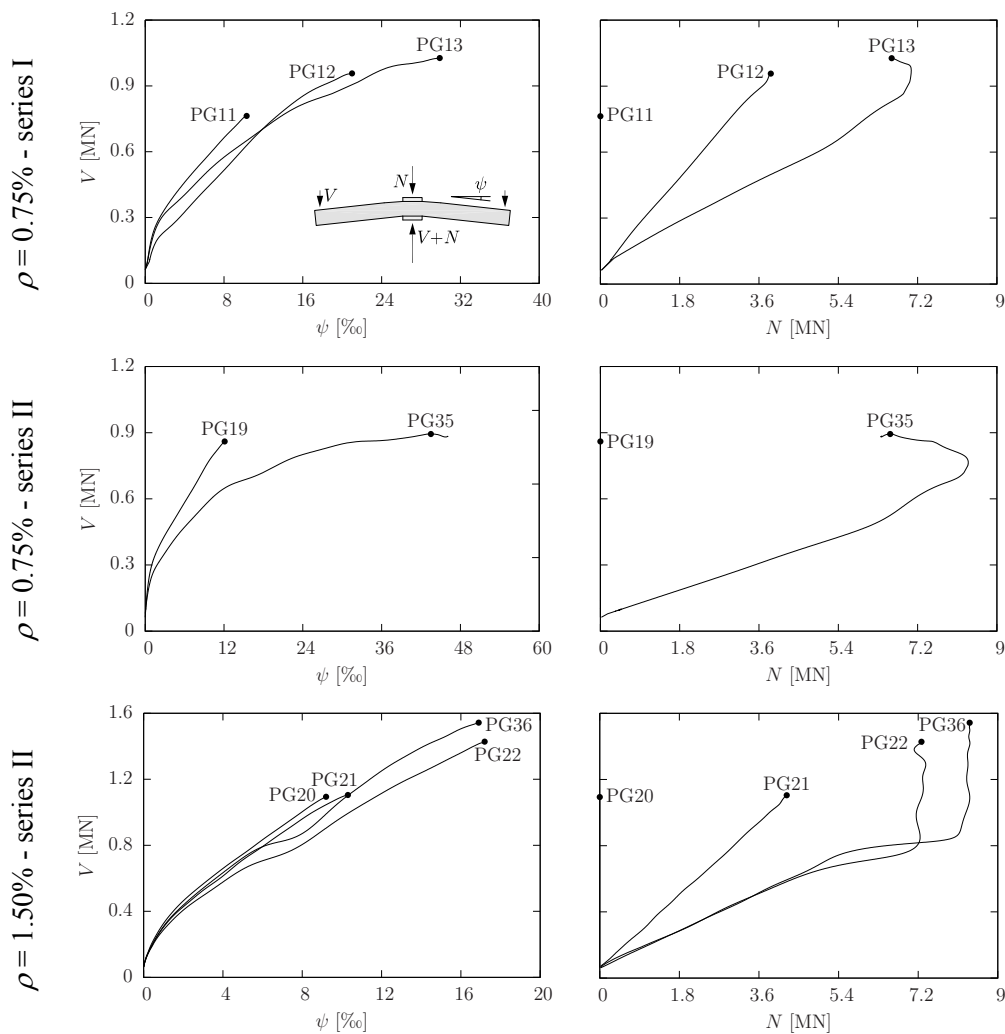
Fig. 4 Slab load (V) – rotation (ψ) curves and slab load (V) – column load (N) curves for all specimens

3 Main results and conclusions

The experimental results as well as their theoretical investigation [1,2,4] show that:

1. Specimens can carry column loads significantly larger than the uniaxial compressive strength of the concrete of the slab (refer to **Tab. 1**). This can be explained by the flexural reinforcement of the slab, which acts as confinement reinforcement in this region [2].

2. For specimens failing in punching shear, the load applied to the slab (V) can be increased if column loads exceeds the uniaxial compressive strength of concrete (refer to **Fig. 4**). This experimental finding has proven to be physically possible since crushing of concrete between columns leads to its lateral expansion and thus acts as a prestressing (reducing crack widths) in the shear-critical region [2].

3. For very large column loads and moderate flexural reinforcement ratios (refer to specimens PG13 and PG35 **Fig. 4**), the failure mode can change from (brittle) punching shear to a plastic mechanism with significant deformation capacity.

4. The observed results can be explained and predicted using the fundamentals of the critical shear crack theory [3] and the theory of plasticity. More details can be found elsewhere [1,2,4]

References

[1] Guidotti R.: Punching of flat slabs subjected to large column loading (in French: Poinçonnement des planchers-dalles avec colonnes superposées fortement sollicitées), Thèse EPFL n° 4812, 230 p., Lausanne, Switzerland, 2010

[2] Guidotti R., Fernández Ruiz M., Muttoni A., Punching of flat slabs under large column loads (in German: Durchstanzen von Flachdecken bei hohen Stützenlasten), Beton- und Stahlbetonbau, 105, 19-26, Berlin, Germany, 2010

[3] Muttoni A., Punching shear strength of reinforced concrete slabs without transverse reinforcement, ACI Structural Journal, V. 105, N° 4, pp. 440-450, USA, 2008.

[4] Guidotti R., Fernández Ruiz M., Muttoni A., Crushing And Flexural Strength Of Slab-Column Joints, Engineering Structures, Elsevier, accepted for publication.

Roberto Guidotti
✉ École Polytechnique Fédérale de Lausanne
ENAC - IBETON, Station 18, CH-1015 Lausanne, Switzerland
☎ +41 21 693 2886
🕮 +41 21 693 5884
☺ roberto.guidotti@a3.epfl.ch
URL http://ibeton.epfl.ch

Miguel Fernández Ruiz
✉ École Polytechnique Fédérale de Lausanne
ENAC - IBETON, Station 18, CH-1015 Lausanne, Switzerland
☎ +41 21 693 2886
🕮 +41 21 693 5884
☺ miguel.fernandezruiz@epfl.ch
URL http://ibeton.epfl.ch

Aurelio Muttoni
✉ École Polytechnique Fédérale de Lausanne
ENAC - IBETON, Station 18, CH-1015 Lausanne, Switzerland
☎ +41 21 693 2886
🕮 +41 21 693 5884
☺ aurelio.muttoni@epfl.ch
URL http://ibeton.epfl.ch