PUNCHING TESTS ON R.C. FLAT SLABS WITH ECCENTRIC LOADING

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SUMMARY

The goal of the

The one-half scale test slabs are square (3 x 3 x 0.15 meter), as is the column (0.3 x 0.3 meter). The slab and column dimensions are constant for all tests. A total of six flat slabs will be tested, with varying eccentricities of the loading: zero, one-half and one time the column dimensions (0, 0.16 and 0.32 m).

A rigid large scale test set-up suitable for the testing of eccentrically loaded flat slabs was built. It allows the introduction of an eccentric force using a single jack applied on a specially shaped column.

A survey of design codes world wide confirm the first tests results which indicate a strong diminution of the punching load with increased eccentricity (up to 36%). The Model Code CEB-FIP 90 seems to give the best estimate of the punching strength with an eccentricity.
Some of the slabs include shear reinforcement, which leads to a more ductile behaviour.

Keywords: punching shear; eccentric loading; reinforced concrete, large scale testing.

1. INTRODUCTION

In a building, the columns have essentially the goal the transmitter vertical loads to the foundation. Nevertheless it is quite impossible to avoid the transmission of a moment form slab into columns. The origin of this moment could be asymmetrical load, unequal span, difference of shrinkage of two slabs, creep, horizontal forces like wind or earthquake. Some actual codes are taking in account the combination between normal force and moment in the calculation of the punching resistance. Those codes are derived from plat theory which give

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2. EXPERIMENTAL PHASE

2.1 Test set-up and materials

Tests were carried out in the laboratories laboratory of the Swiss Federal Institute of Technology. They were performed on six large flat slabs with a square concrete column in the middle of the slab.

A special shape was given to the column so that it was possible to apply the axial force with an eccentricity. The moment increases linearly with the force.

The slab are square (3 x 3 x 0.15 meter), as is the column (0.3 x 0.3 meter). This dimensions are constant for all tests. The nominal total thickness *h* of the slab is 150mm and the nominal average effective depth is 121mm. The slabs are simply supported on knife edges fixed on steel beams so that the edge are free to lift. A total of six flat slabs have been tested, with varying eccentricities of the loading: zero, one-half and one time the column dimensions (0, 0.16 and 0.32m, see Fig. 1 and 2).

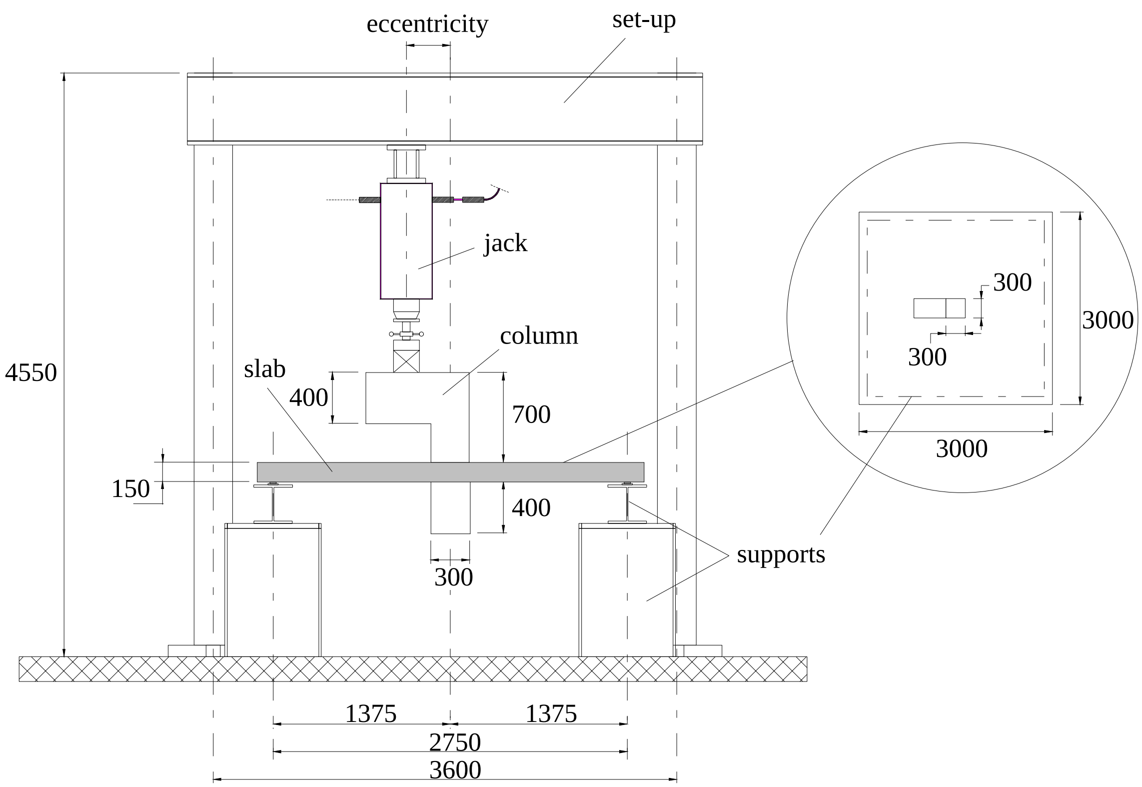


Fig. 1 Test set-up (dimension in mm)

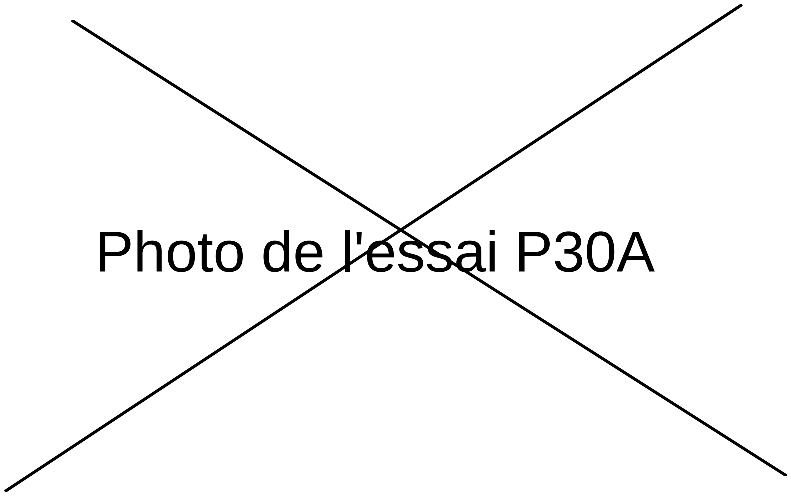
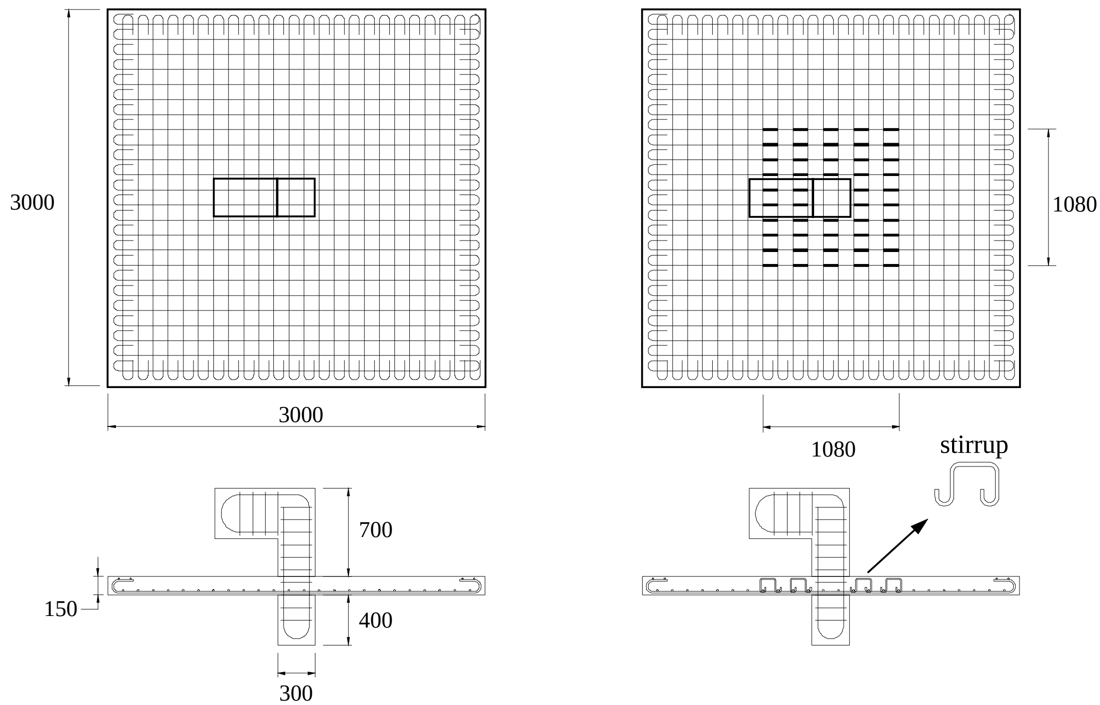


Fig. 2 Slab P30A during testing

The cylinder compressive strength of the concrete f_{cc} is 35MPa. The mean ratio in each direction of the flexural reinforcement ρ is 1.0% and 1.3% respectively for the slabs without and with shear reinforcement. The shear reinforcement consists in stirrups of 10 mm diameter. The layout of the reinforcement is shown in Figure 3.



Without shear reinforcement	**With shear reinforcement** (48 stirrups of Ø10)
Slabs P0A, P16A, P30A	Slabs PP0A, PP16A, PP16B
Ø14, s = 120mm (ρ_{long} = 1.0%)	Ø16, s = 120mm (ρ_{long} = 1.3%)

Fig. 3 Longitudinal and shear reinforcement (dimension in mm)

2.2 Loading procedure

The tests were performed with an deformation-controlled hydraulic jack with a constant loading rate of 4kN per minute. During every test, the load was applied in steps of 40 kN. Between load steps the deformation was kept constant for 10-15 minutes. During this time the crack pattern was inspected and the manual measurement of radial and tangential deformation at the bottom surface of the slab (tension) were performed.
After the peak load was reached, the deformation was further increased to record the post-punching behaviour of the slabs. The tests ended when the column had penetrated into the slab or when the rotation of the column exceeded 5%.
Automatic data acquisition devices was taken every minute on a computer.

2.3 Measuring devices

- 35 inductive displacement sensors;
- 32 strain gauges (Omega gauges) on the compressive side in radial and tangential direction;

- 4 strain gauges glued on the longitudinal bars near the column in the punching zone;
- 3 inclinometers on the column;
- 2 inductive displacement sensors measuring the opening of the punching cracks across the section of the slab;
- 1 force captor on the jack
- 66 manual measurements on the tensile side to measure opening of the cracks (only possible between load steps).

3. FIRST RESULTS

Since data analysis is not yet complete, only a partial the results are presented. A complete test report will be published during the summer 1998.

3.1. Influence of the eccentricity

A total of six slabs were tested with 3 different eccentricities. Because of a higher loading, longitudinal reinforcement was increased to 1.3% for all the slabs with shear reinforcement.

The first graph presented in Figure 4 shows the maximum defections of the slab versus force apply by the hydraulic jack. The slope of the curves at the beginning are almost similar for all slabs because it depend only on the shape and the module of elasticity of the slab. Differences of rigidity see on curves P0A and P30A are coming form the glue using to equalise the contact between the slab and the supports. For the other slabs this glue wasn't used. For all slabs the first crack appears approximately for the same force independent of the eccentricity (between the second and the third load step). After that the number of cracks
Table 1 gives the ultimate load and the reduction compared with the centrally loaded case.

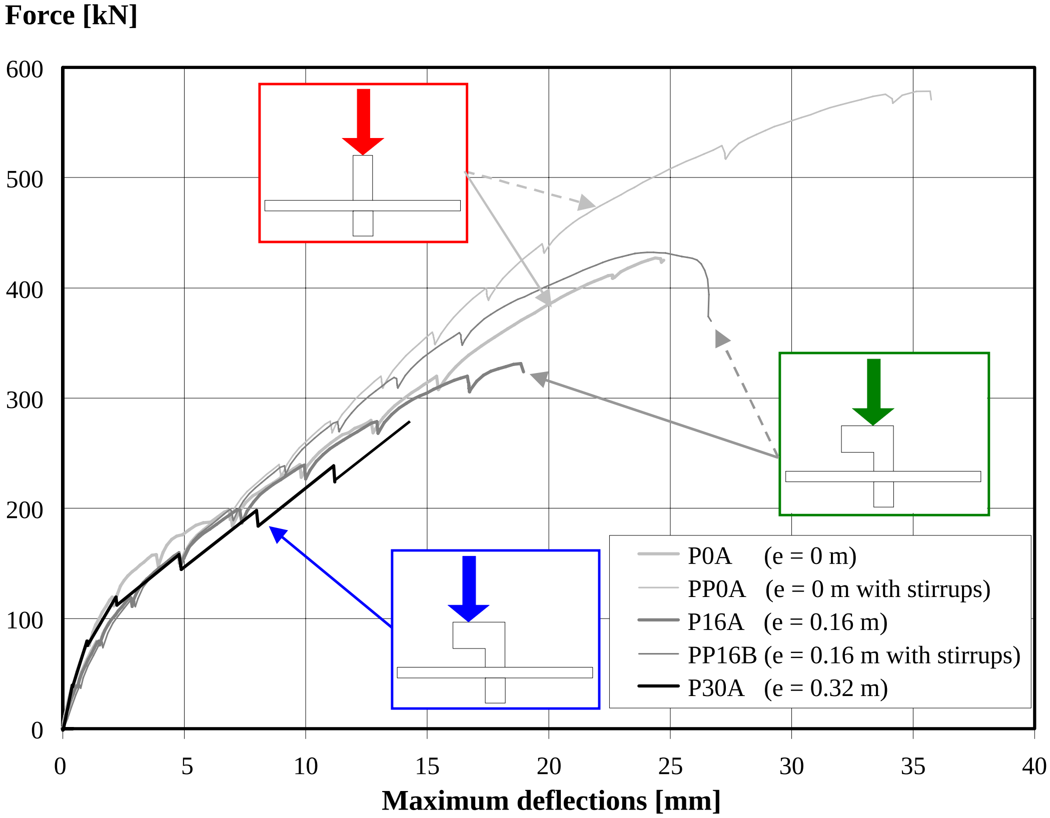


Fig.4 Force in the jack versus maximum vertical slab deflection

	Without shear reinforcement			With shear reinforcement	
Slab	**P0A**	**P16A**	**P30A**	**PP0A**	**PP16B**
Eccentricity [m]	0	0.16	0.32	0	0.16
Longitudinal reinforcement	1.0%	1.0%	1.0%	1.3%	1.3%
Ultimate load [kN]	423	331	270	578	432
Reduction 1 - Px/P0A	0%	22%	36%	0%	25%

Tab. 1 Parameters, ultimate load and influence of the eccentricity of the different slabs

The eccentricity seems to have a strong influence on the ultimate load. The decrease in ultimate load is about 22 % for an eccentricity of one-half of the column dimension (0.16 m) and 36 % for an eccentricity of one column dimension (0.32 m).

All slabs without shear reinforcement failed in a brittle manner with a sudden loss of capacity. However, the eccentricity reduced the brittleness of the failure. The failure mode could be defined as a flexural punching because it is due to a combination of shear and moment in the slab.

3.2. Influence of the shear reinforcement

The presence of shear reinforcement increases the ultimate load by about 30-35% depending on the eccentricity. The slab reached a yield plateau and exhibited a ductile behaviour to failure (see Fig. 4, curve PP16B). The use of stirrups seems to guarantee a better behaviour as far as the eccentricity is concerned. The reduction of the ultimate load due to an eccentricity of 0.16 m is approximately the same than without shear reinforcement (25%, see Tab. 1). In this case, the stirrups seems to have no effect in reducing the influence of an eccentricity.

4. INFLUENCE OF ECCENTRICITY PROPOSED BY ACTUAL CODES

A total of seven codes were examined with regard to their provisions concerning punching shear. The form and the parameters are similar. However the value of those parameters vary significantly. The table 2 shows the punching strength for the tested slabs without eccentricity according to the various codes.

Code	ACI318/ 89	SIA 162	Model Code 90	British Dratf	SniP Code	Eurocode 2	BBK79
Country	USA	CH	Europe	GB	Russia	Europe	Sweden
V_{Rd}[kN]	297	258	245	238	217	188	149
Eccentricity taken into account	YES	NO	YES	YES	?	Partially	YES

Tab 2 Punching resistance V_{Rd} according to the different code (centric load)

As we can see in the table 2, the punching resistance varies a lot from code to code (a factor two between BB79 and ACI318). It is therefore difficult to use this comparison to estimate the influence of the eccentricity.

The manner to take into account an eccentricity of the load is different in those codes. The SIA162 (Swiss Code) gives no rule about this subject. The Eurocode 2 gives a unique coefficient of $\beta = 1.15$ (for an interior column) which is to multiply the ultimate design load V_{sd}. The other codes give a linear formula between the contribution of the force and the moment. The figure 5 shows a comparison between tests and codes. Tests seems to be perfectly linear with the eccentricity as predicted by code. The influence of this eccentricity is over evaluated by all codes. Nevertheless the Model Code 90 and the British Draft give the best estimation of this influence. In this case using the SIA 162 for an eccentricity more than 0.32m could be dangerous.

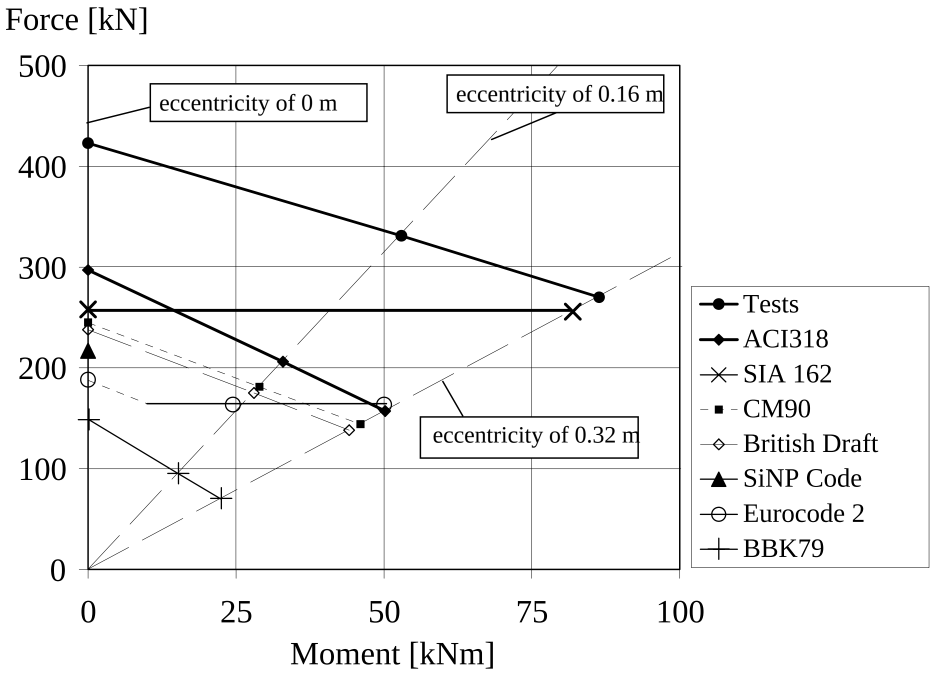


Fig. 5 Influence of the eccentricity according to different codes

5. CONCLUSIONS AND FUTURE WORK

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