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PUNCHING TESTS ON RC FLAT SLABS WITH ECCENTRIC LOADING

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SUMMARY

Because of unsymmetrical loading, unequal spans or boundary conditions, moment transfer from slab to column is practically always present in flat slabs. The presence of moments reduces the punching resistance of slabs. To investigate this phenomenon, a total of six flat slabs were tested with normal concrete, varying eccentricities of the loading: zero, one-half and one time the column dimensions (0, 0.16 and 0.32 m). Slabs are square (3 x 3 x 0.15 m), as is the column section (0.30 x 0.30 m). Those dimensions are constant for all tests. A survey of design codes worldwide indicate a strong diminution of the punching load with increased eccentricity (up to 36 %). This is confirmed by the first test results. The Model Code CEB-FIP 90 and the British Standards seem to give the best estimate of the punching strength with an eccentricity.

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

1. INTRODUCTION

In buildings, columns have essentially the purpose to transmit vertical loads to the foundation. Nevertheless it is quite impossible to avoid transmission of a moment from slab into columns. The origin of this moment could be asymmetrical loading, unequal span, differential shrinkage between two slabs, creep, horizontal forces like wind or earthquake. Some current codes are taking in account the combination of normal force and moment in the calculation of punching resistance. Those codes are derived from plate theory and based on limited number of tests. Most tests were performed on small scale specimens with thin slabs (thickness h = 0.07 to 0.1 m) and using micro concrete (Regan and al, 1979; Moe, 1961). There is a lack of punching tests of large slabs with an eccentricity. The interaction between an eccentricity of the force and the use of shear reinforcement was never investigated regarding to punching.

This research consists of an experimental phase in the laboratory followed by an analytical phase attempting to quantify the moment transfer from slab to column. The

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experimental phase consists in a series of large scale laboratory tests (h = 0.15 m) using normal concrete, varying the eccentricity. Some tests include shear reinforcement.

2. EXPERIMENTAL PHASE

2.1 Test set-up and materials

Tests were carried out in the structures 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 is thus proportional to the force.

Figure 1 shows the test set-up. The slab are square (3 x 3 x 0.15 m), as is the column (0.30 x 0.30 m). This dimensions are constant for all tests. The nominal total thickness *h* of the slab is 0.15 m and the nominal average effective depth is 0.121 m. The slab is 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, approximately one-half and one time the column dimension (0, 0.16 and 0.32 m).

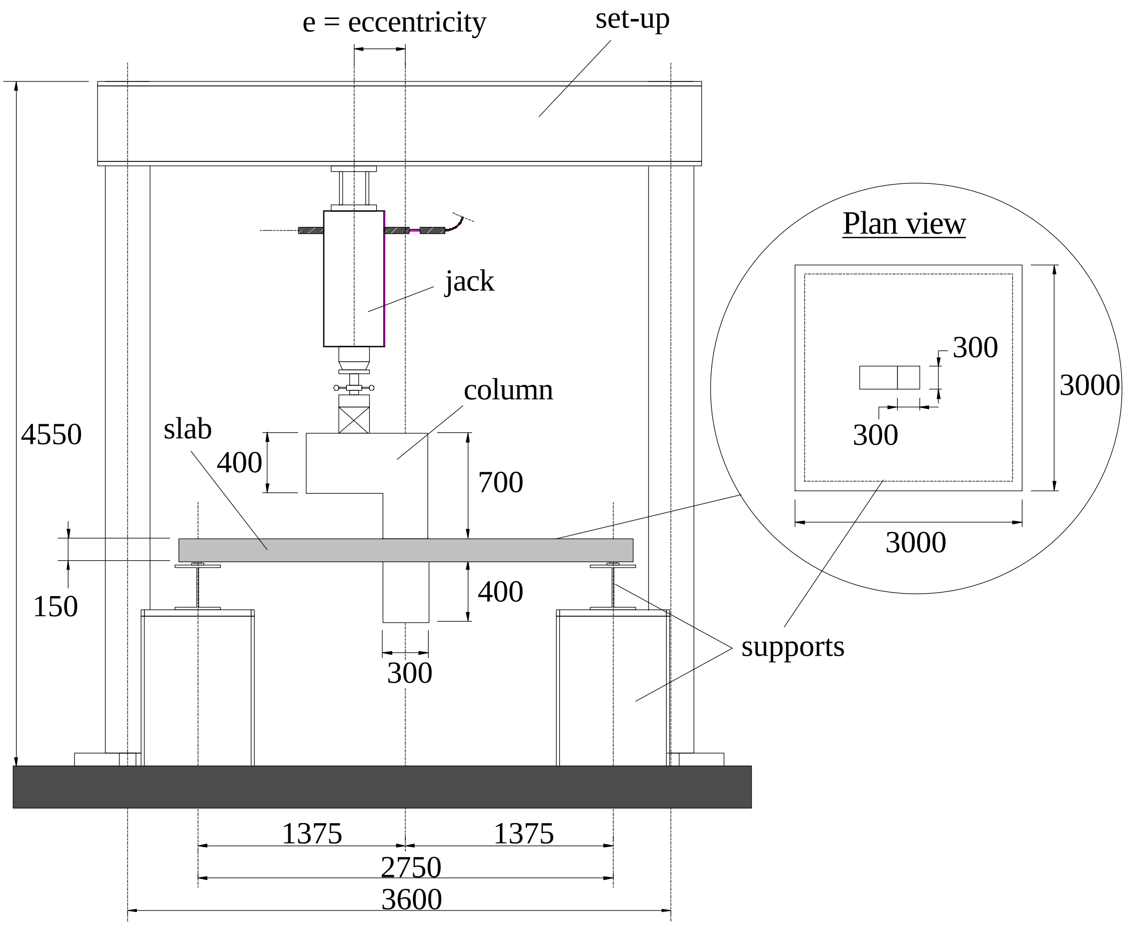

Fig. 1 Test set-up (dimensions in mm)

The cylinder compressive strength of the concrete f_{cc} is 35 MPa. The mean ratio in each direction of the flexural reinforcement r 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 2.

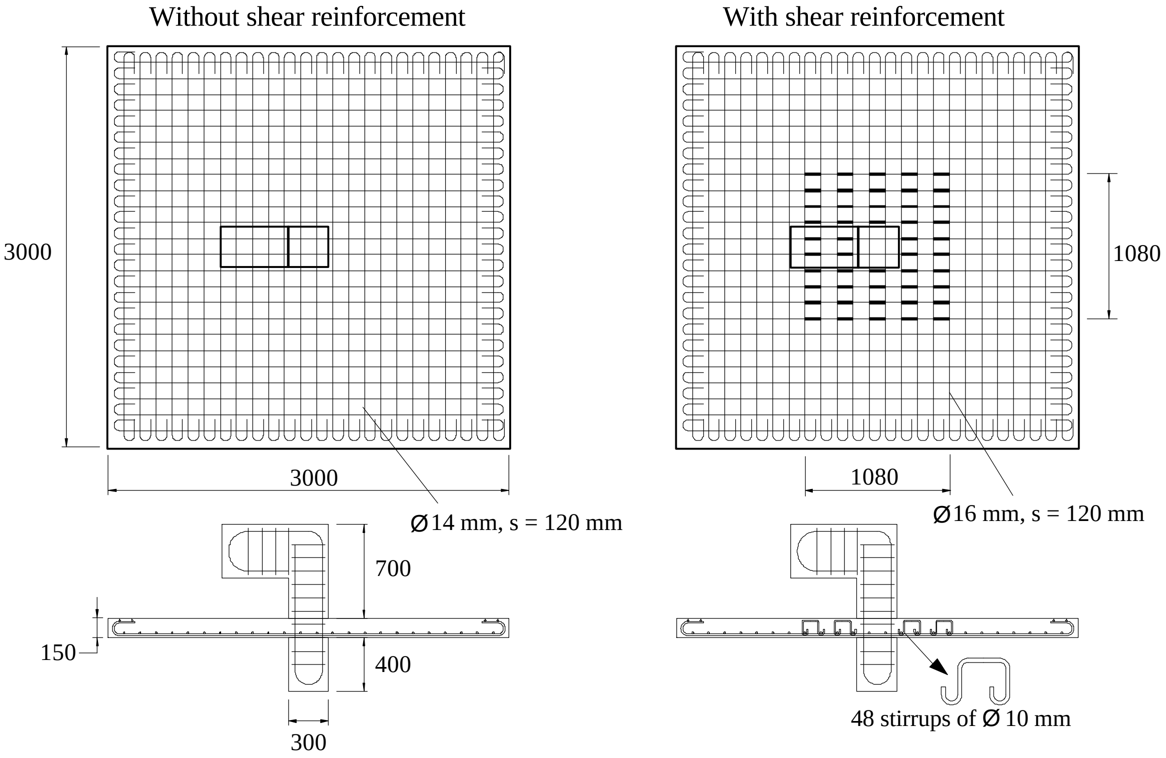

Fig. 2 Longitudinal and shear reinforcement (dimensions in mm)

2.2 Loading procedure

The tests were performed with a deformation-controlled hydraulic jack with a constant loading rate of 4 kN 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 for inspection and measurements.

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 %.

2.3 Measurements

Automatic data acquisition devices was taken every minute on a computer. Crack pattern was inspected and the manual measurement of radial and tangential deformation at the bottom surface of the slab (tension) were performed. The measuring devices are:

- 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 sensor on the jack;
- 66 manual measurements (Demec extension gauges) on the tensile side to measure opening of the cracks (only possible between load steps).

Figure 3 shows the slab during the test with the measurements devices (inductive displacement sensors, force sensor on the jack and strain gauges).

Fig. 3 Slab P30A during testing

3. PRELIMINARY RESULTS

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

Figure 4 shows the maximum slab defection versus the force applied by the hydraulic jack. The slope of the curves at the beginning are almost identical for all slabs because it depends only on the shape and the modulus of elasticity of the slab. Differences in rigidity observed in curves P0A and P30A are caused by the cement used to equalise the contact between the slab and the supports. For the other slabs this cement was not used. For all slabs the first crack appears approximately at the same load level independently from the eccentricity (between the second and the third load step at approximately 100 kN). After that first cracks developed, the slope of curves is governed by the longitudinal reinforcement. The slope for the two slabs with shear reinforcement (ρ_{long} = 1.3 %) is higher than without shear reinforcement (ρ_{long} = 1.0 %).

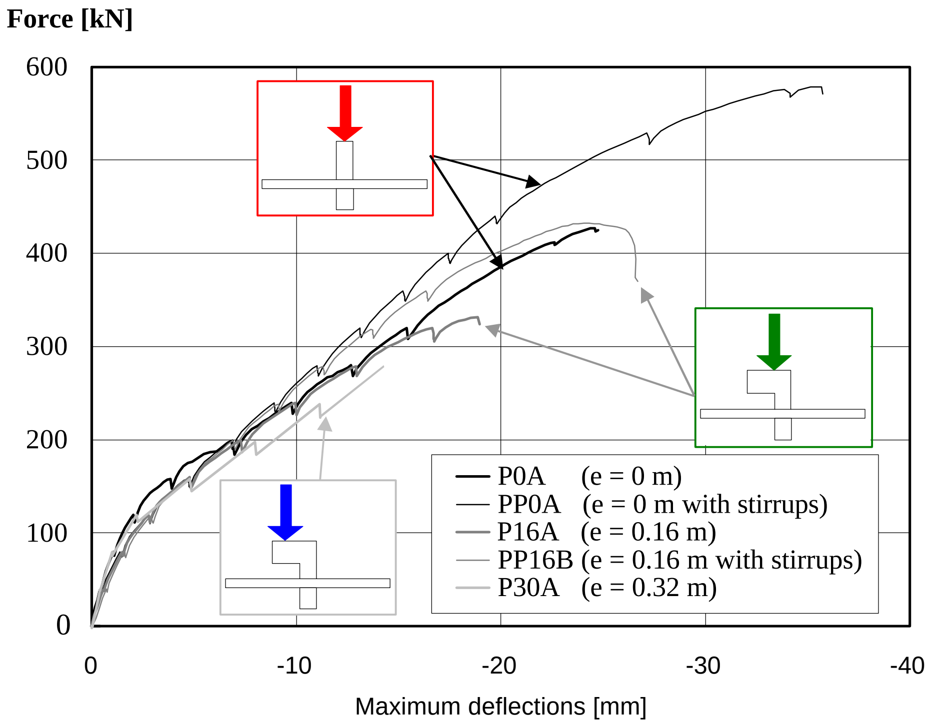

Fig.4 Force in the jack versus maximum vertical slab deflection

Table 1 gives the ultimate load and the reduction compared with the centrally loaded case. The eccentricity has a strong influence on the ultimate load. The decrease in ultimate load is about 22 % for an eccentricity of 0.16 m and 36 % for 0.32 m.

	Without shear reinforcement			With shear reinforcement	
Slab	P0A	P16A	P30A	PP0A	PP16B
Eccentricity e [m]	0	0.16	0.32	0	0.16
Longitudinal reinforcement	1.0 %	1.0 %	1.0 %	1.3 %	1.3 %
Ultimate load	423 kN	331 kN	270 kN	578 kN	432kN
Reduction compared to e = 0	0 %	22 %	36 %	0 %	25 %

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

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. This remark is true only of a specimen tested in deformation-controlled conditions.

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).

4. INFLUENCE OF ECCENTRICITY PROPOSED BY DESIGN 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 predicted punching strength for the tested slabs without eccentricity according to the various codes.

Code	ACI318 (USA)	SIA 162 (CH)	MC 90 (Europe)	BS 8110 (GB)	SniP Code (Russia)	EC 2 (Europe)	BBK79 (S)
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)

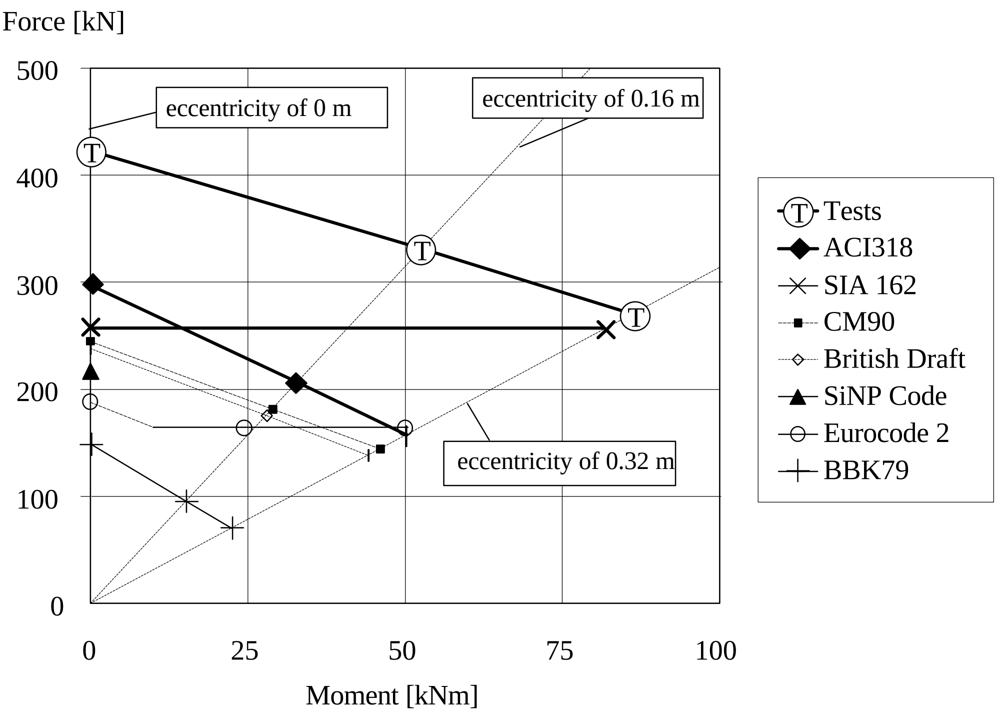

Fig. 5 Influence of the eccentricity according to different codes

As can be seen in 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.

Figure 5 shows a comparison between tests and codes The manner to take into account an eccentricity of the load varies from code to code. The SIA162 (SIA 162, 1989) gives no rule about this subject (horizontal line, Fig. 5). For eccentricities more than 0.32 m, using this code could be dangerous. The Eurocode 2 (Eurocode 2, 1992) gives a constant coefficient of b = 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. Tests seems to be perfectly linear with the eccentricity as predicted by code. The influence of this eccentricity is overevaluated by all codes, especially by the Swedish Code (BBK79, 1979). Nevertheless the Model Code 90 (Model Code CEB-FIP, 1990) and the British Regulation (BS 8110, 1985), give the best estimation of this influence.

5. CONCLUSIONS AND FUTURE WORK

Tests on large flat slabs with varying eccentricities are presented. The results indicate a strong diminution of the punching load with increased eccentricity (up to 36 %). This diminution is linear with increased eccentricity. The Model Code CEB-FIP 90 and the British Standards seem to give the best estimate of the punching strength with an eccentricity. The use of stirrups appears to guarantee a better behaviour as far as the eccentricity is concerned.

In the future, a parametric study will be done to estimate the magnitude in actual buildings, taking into account local cracking around the columns. The effect of moment induced by imposed deformation, as for example shrinkage in very long buildings without joints, will be investigated. Guidelines will be proposed to optimise the size of the different components of building to limit the problems related to eccentricity.

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