Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 52(11) (2021) 707-710
DOI: 10.22060/ceej.2019.16471.6245

An experimental study on post-punching behavior of flat slabs to prevent progressive collapse

S. Sarvari [1], M. R. Esfahani [2*]

[1] Ph.D. Student, Faculty of Engineering, Ferdowsi University of Mashhad
[2] Professor, Faculty of Engineering, Ferdowsi University of Mashhad

ABSTRACT: If unpredictable loads are applied to the flat slab-column connections, punching shear failure occurs with almost no warning signs. According to the brittle manner of this failure, the load carried by the slab-column connection redistributes to adjacent supports and causes overloading to these supports. Due to this overloading and brittle nature of punching shear failure, progressive collapse may happen both horizontally or vertically. In order to prevent the progressive collapse of flat slab-column connections, it is necessary to provide a secondary load carrying mechanism after punching shear. In this Paper, Suggestions for establishing a supporting mechanism in the flat slab connections after punching failure are proposed. For this purpose, an experimental study was performed to investigate the post-punching behavior of 9 slab specimens with various reinforcement layouts and concrete covers. The effects of integrity, compressive and bent-up reinforcements, diameter of tensile reinforcements, and concrete cover of tensile reinforcements on the post-punching behavior of slab-column connections were studied. The results of the experiments show that the integrity reinforcements significantly improve the post-punching strength. The compressive reinforcements may not increase post-punching strength. The increase of the concrete cover of the tensile reinforcements and decrease of the diameter of the tensile reinforcement result in an increase of the post-punching strength. The bent-up reinforcement increases the punching and post-punching strengths, simultaneously.

Review History:

Received: 2019-06-02
Revised: 2019-07-21
Accepted: 2019-07-24
Available Online: 2019-07-30

Keywords:

Post-Punching strength
Flat slab
Progressive collapse
Integrity reinforcement
Punching shear failure

1.INTRODUCTION

After a punching shear strength failure, the load carried by the slab-column connection redistributes the load to adjacent connections, and hence, the load increases rapidly in these connections. Consequently, they fail in punching shear due to overloading. This would result in the fall of the slab onto the slab below, thereby propagating the collapse both horizontally and vertically throughout the structure and could lead to progressive collapse of the structure [1]. The key to avoiding these failures is to provide a secondary load carrying mechanism after a slab-column connection has failed in punching shear [1,2]. After formation of the shear punching crack and in the absence of shear reinforcement, aggregate interlocking reduces quickly. Therefore, dowel action plays a significant role in transferring shear, because the only connection between the slab and the cone is the tensile and integrity reinforcement [1,2].

Hawkins and Mitchell [3] proposed possible defenced strategies that influence progressive collapse in flat slab structures. Finally, they recommended the provision of effectively continuous bottom reinforcement passing through the columns, later termed structural integrity reinforcement. Mitchell and Cook [2] stated that "Resisting mechanisms which develop after the occurrence of initial failures are described along with simple design and detailing recommendations necessary to enable the damaged slab to hang from its supports. These design and detailing requirements result in effectively continuous bottom bars along column lines that are well anchored into the column or support regions". Melo and Regan [4] shows that bottom bars passing through a column and anchored in the slab to either side of it can be highly effective in increasing the post-punching resistance of a slab-column connection. The final resistance provided by the bottom bars appears to be governed either by the destruction of the concrete in the zone where they are anchored in the slab or by the fracture of the bars themselves. They reported that the angle of inclination of the integrity reinforcements at failure in the vicinity of the column face varied from 22° to 26°. Mirzai and Muttoni [5] tested various reinforcement layouts tensile reinforcement, integrity reinforcement and bent-up integrity bars. They concluded that tensile reinforcement provides a limited post-punching capacity when it is not suitably anchored on the soffit of the slab and the integrity reinforcement can increase the residual strength of flat slabs. They state that "Bent-up bars generally perform better than straight bars". They advised to Use high-ductility reinforcement for the integrity bars [5]. Habibi et al. [1] showed that increase of the slab thickness increases the post-punching resistance of slab–column connections.

In this paper, an extensive experimental campaign was performed to investigate the post-punching behaviour of 9

*Corresponding author's email: esfahani@ferdowsi.um.ac.ir

Table 1. Summary of test results

Series No.	*Spec. No.*	Punching strength V_P [kN]	Punching Displacement w_P [mm]	Maximum post-punching strength $(V_{PP})_{max}$ [kN]	Maximum post-punching displacement $(w_{PP})_{max}$ [mm]	Ratio post-punching to punching strength $\frac{(V_{pp})_{max}}{V_P}$	Ratio post-punching to ACI punching $\frac{(V_{PP})_{max}}{V_{ACI}}$
Series 1	SP-1	246	30	101	111	41%	59%
	SP-2	271	27	232	138	86%	136%
	SP-3	261	31	261	120	100%	153%
Series 2	SC-1	297	28	270	132	91%	158%
	SC-2	310	37	305	147	98%	179%
Series 3	SR-1	272	36	283	135	104%	166%
	SR-2	250	36	195	135	78%	114%
Series 4	SB-1	375	28	265	66	71%	155%
	SB-2	292	25	235	120	80%	138%

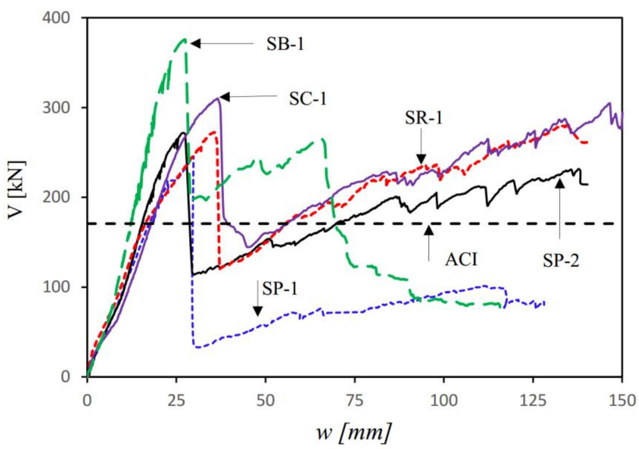

Fig. 1. Shear-displacement behavior of some specimens (One specimen of each Series)

slabs with various reinforcement layouts and cover concrete. The purpose of the current study is research on the effects of integrity, compressive, bent-up integrity, and bent-up additional reinforcements, diameter of tensile reinforcements, and concrete cover of tensile reinforcements on the post-punching behaviour of slab-column connections.

2. METHODOLOGY

In this experimental study, half-scale specimens were constructed in four series. In all specimens, the ratio of the tensile reinforcements and the concrete cover of the compressive and integrity reinforcements are 0.62% and 15 mm, respectively. Series 1 consisted of three specimens. The SP-1, SP-2 and SP-3 included tensile reinforcements, tensile and integrity reinforcements, and tensile, integrity and compressive reinforcements, respectively. The series 2, 3, and 4 were used to the effects of concrete cover of the tensile reinforcements, diameter of the tensile reinforcements, and the bent-up reinforcements on the post-punching strength, respectively. Series 2 consisted of two specimens. The reinforcements of these specimens are similar to the SP-2 specimen. In SC-1 and SC-2 specimens, the top clear covers (cover of tensile reinforcement) are 25 and 35 mm, respectively. Series 3 consisted of two specimens. The ratio of the tensile reinforcement is equal to SP-2 specimen (0.62%). In the SR-1 and SR-2, distance and diameter of the tensile reinforcement decrease and increase, respectively. The other details of these specimens are similar to those of the SP-2 specimen. Series 4 consisted of 2 specimens. In the SB-1 specimen, bent-up bars were used as integrity reinforcement with an angle of inclination of 45° and bent from the column face. In the SB-2 specimen, additional bent-up bars were placed in crossover arrangement around the column. Table 1 shows the summarized results of these experiments. Shear-displacement behavior of some specimens is shown in Fig. 1.

3. CONCLUSION

Based on the result of the present study, Integrity reinforcements significantly increased post- punching strength. These reinforcements can develop tensile membrane action and prevent progressive collapse by alternative load paths to transfer the load. These reinforcements did not have much influence on the punching strength. In the column strip, compressive bars (except integrity reinforcements) did not have much influence on the punching and post-punching strength. Increase of the concrete cover (in tensile region) can enhance punching and post-punching strength. Concrete shear strength increases with increase concrete thickness. Hence, punching shear strength enhances with increase of the cover concrete (concrete thickness). Increase of the cover concrete enhances dowel action and delays concrete spalling. Hence, post-punching strength increases. Decrease of the diameter reinforcements (tensile reinforcement) increase post-punching strength. Bent-up integrity reinforcements significantly increase punching and post-punching strength. Additional bent-up reinforcements were not effective on the post-punching strength. These reinforcements slightly increased punching strength.

REFERENCES

[1] F. Habibi, E. Redl, M. Egberts, W. Cook, D. Mitchell, Assessment

of CSA A23.3 Structural integrity requirements for two-way slabs, Canadian Journal Civil Engineering, 39(4) (2012) 351-361.
[2] D. Mitchell, W.D. Cook, Preventing Progressive Collapse of Slab Structures, Journal of Structural Engineering, 110(7) (1984) 1513-1532.
[3] N.M. Hawkins, D. Mitchell, Progressive collapse of flat plate structures, ACI Journal, 76(10) (1979) 775-808.
[4] G.S. Melo, P.E. Regan, Post-punching resistance of connections between flat slabs and interior columns, Magazine of Concrete Research, 50(4) (1998) 319-327.
[5] R.M. Fernández, Y. Mirzaei, A. Muttoni, Post-Punching Behavior of Flat Slabs, ACI Structural Journal, 110 (2013) 801-812.

HOW TO CITE THIS ARTICLE

S. Sarvari, M.R. Esfahani, An experimental study on post-punching behavior of flat slabs to prevent progressive collapse, Amirkabir J. Civil Eng., 52(11) (2021) 707-710.

DOI: 10.22060/ceej.2019.16471.6245