

Proceedings of the 4th International Conference on Recent Innovation in Engineering ICRIE 2023, University of Duhok, College of Engineering, 13th – 14th September 2023 (Special issue for Passer journal of basic and applied sciences) Paper No. 34

Ultra-high-performance fiber-reinforced concrete flat slabs' punching shear resistance as a function of drop panel thickness

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ABSTRACT

Ultra-high-performance concrete including fibers (UHPFRC) is used to build skyscrapers, towers, and bridges. This type of concrete may have smaller skeletal components than normal concrete. However, flat slabs are thicker than reinforced concrete slabs. Brittle punching shear failure may happen rapidly and abruptly in flat slabs. The punching load was applied to four two-way internal UHPFRC-supported flat slabs: three reinforced concrete flat slabs with 10mm, 14mm, and 18mm drop panels and one control reinforced concrete slab without drop panels. The drop panel thickness enhanced punching shear resistance by 40% at fracture load and 48% at ultimate stress. In addition, deflection, shear strain at the concrete surface, strain in reinforcement, rotation at supports, and fracture inclination angles between top and bottom fibers improved by 30%, 316 percent, 74%, 385 percent, and 1.01 percent at peak load, respectively.

KEYWORDS: Flat slabs, Micro steel fibers, Punching shear resistance, Thickness of drop panels, and UHPFRC

1 INTRODUCTION

Slabs that provide column support in the absence of beams are often referred to as reinforced concrete flat slabs. Multi-story structures, including residential buildings, hotels, hospitals, and parking garages, frequently employ flat slabs. This is primarily attributed to their room layout flexibility, expedited construction process, diminished building height, and simplified mechanical and electrical service installation. Flat slabs possess certain imperfections, with notable drawbacks including limitations on mechanical ducting and deflection at the midpoint strip, which could prove to be crucial [1].

When the flat slab is progressively subjected to increased loading, it induces the punching resistance to shear mechanism or failure. On the tension face of the slab surrounding the column, the initial fracture appears as a result of a negative moment near the column. Insufficient strength against shear in a structure subjected to additional loads will result in the outgrowth of a truncated pyramid of concrete from the slab [2].

A local failure scenario, punching shear is induced by the buildup of local stresses in the vicinity of the supporting column. Despite the existence of several methods to enhance the punching shear capacity of reinforced-concrete flat plate slabs, their practicality is often restricted. For instance, conventional stirrupbased shear reinforcing is only suitable for slabs exceeding 150 mm in depth [3]. A fracture develops in the slab in the vicinity of the column when it is subjected to lateral seismic loading, which induce an asymmetrical moment that boosts shear stresses. Cracks proliferate throughout the overall height of the slab at different angular degrees with respect to the slab's base, leading to punching shear failure and fracture propagation [4].

In lieu of a drop panel, the slab may be thickened to the same depth as the column area [4]. In areas where the column is likely to break through the slab, the thickness of the drop panel and the area that the drop

panel adequately covers both actively contribute to the reduction of shear stresses. Moreover, it stiffens the slab and reduces deflection by increasing the resisting moment at the location where negative moments are greatest. Assumedly, the critical section of the punching shear occurs d/2 from the column face. Additionally, when the drop is implemented in a flat slab system, the half depth of slab distance from the drop's face on the column is considered [5].

RPC stands as an alternative designation for ultra-high-performance concrete. Composed of silica fume, fine silica grains, Portland cement, a high-range water reducer, and water, it is a material of exceptional strength. The addition of organic or steel fibres to the composition transforms the material into UHPFRC. This variant is characterised by a dramatically improved compressive strength ranging from 150 to 270 MPa and allowing it to withstand bending moments, even after initial cracking, and the capability of obviating the need for steel reinforcement in certain applications. In order to withstand hostile environments and severe loads, such as those induced by explosions, earthquakes, or effects, UHPFRC is implemented in protective structures including impenetrable coverings and structural element components. UHPC is distinguished by its exceptional flowability, enabling it to be sprayed with a smooth surface and very dense reinforcement; it also exhibits swift strength development, the capability of fortifying individual intact members through local or complete filling. UHPC possesses a wider array of applications due to these characteristics, which encompass buttresses for high pressures, narrow supports, and lofty structures and bridges [6].

2 LITERATURE REVIEW

For punching shear resistance in the absence of drop panels, the behaviour and strength of reinforcedconcrete flat slabs produced with ultra-high-performance concrete reinforced with fibres are examined. Furthermore, it offers contextual details regarding the existing benchmarks for punching shear strength, the manner in which certain researchers have elevated the peak load associated with punching shear, and the overarching mechanism of failure.

An experimental protocol was proposed by Liao et al. (2012) [7] for plain and reinforced shallow UHPC slabs. By conducting six UHPC experiments and one sample of normal-strength concrete, the interaction between slab thickness, reinforcement ratio, and fiber contents at the crack and ultimate loads was investigated. The positive impact of steel reinforcement bars in conjunction with UHPC on flexural and shear strength has been demonstrated in six UHPC tests. They found, through the placement of plastic strains in rebars along a single macrocrack, that an increase in fiber content generally results in a reduction of the strain capacity at the ultimate load.

In their study, Nguyen et al. (2017) [8] examined the impact of the orientation of fibers on the punching shear strength of eight slabs made of high-performance steel fiber-reinforced concrete (HPFRC). Three flat plate slabs produced a two-volume fraction of steel fiber when cast. The findings revealed a significant relationship between the amount of steel fibers, the critical position of the slabs under investigation, and the magnitude of the punching shear failure cone.

In their study, Lampropoulos et al. (2018) [9] examined the correlation between slab thickness and resistance to punching shear. Fifteen UHPC slabs with simple support were subjected to failure testing. With three exceptions, every slab was composed of steel filaments. As a result, the load capacity of the slabs proved substantially enhanced by the inclusion of steel fibers.

In their study, Shoukry et al.2021 [10] determined the punching shear resistance of ten simply supported UHPFC slabs by subjecting them to failure testing. The researchers varied the fibre volume fraction from 3% to 0% and the compressive strength ranged between 56 MPa and 123 MPa. Fibre type and material (polypropylene, steel, or fibreglass) were also employed, alongside fibre shape (end-hooked or corrugated) and fibre size maintaining a constant aspect ratio. While the introduction of larger diameter and length

fibres of steel enhanced the punching shear strength, it had no discernible impact on the initiation of flexural fractures.

In a bid to illustrate the mechanical characteristics of UHPFC, Yan et al. (2021) [11] subjected twelve simply supported reinforced concrete slabs with steel fiber volume fractions ranging from 0% to 4% to failure testing. The influence of steel fibre on the mechanical properties of UHPC was ascertained. According to the findings of the investigation, the working performance of UHPC was impacted by the addition of steel fibre, and the degree of collapse and expansion of UHPC was inversely proportional to the aspect ratio and fibre volume fraction of steel fibre. The steel fibre substantially enhanced the mechanical properties of UHPC. UHPC demonstrated a progressive reduction in compressive strength and a progressive increase in resistance for bending with the augmentation of the aspect ratio of steel fibre, while maintaining a constant amount of steel fibre.

3 RESEARCH OBJECTIVES

As a general, the shear capacity of internal slab-column connections might be increased by employing high-strength concrete. While using drop panels with a constant area and an aspect ratio of 20 micro steel cooper coated fiber in UHPFRC flat slabs might be lead to change the punching shear critical section locations. Therefore, the major goal of this research is to determine the impact of drop panel thickness on punching shear resistance in internal flat slab column connections made of UHPFRC .

4 EXPERIMENTAL PROGRAM

The study at hand used four 620mm x 620mm UHPFRC specimens were poured and tested to show how drop panel thickness affected punching shear capability, as illustrated in the following sections:

4.1 Selection of materials

The materials employed in this work to produce UHPFRC with a strength of more than 150 MPa are discussed in the following paragraphs.For UHPFRC preparation. Tasluja Ordinary Portland Cement Type I, made by TCC, was used in this investigation. The physical qualities satisfy the criteria [12].

Silica fume is employed in this study and the physical parameters of silica fume are present in Table 1. Moreover, the mining sand with physical properties is used, as shown in Table 1. Table 1 depicts the gradation of fine aggregate, which meets the ASTM C33 standard specification [13].UHPFRC is made by mixing ingredients with tap water. It was free of oil, organic debris, and other hazardous materials. For the admixture type F (High Flow PCE 120) used in this concrete mix.

In the study, a 2% volume fraction of micro steel fiber coated with copper was employed to make UHPFRC slabs. To avoid dry balling of fibres and a deterioration in the workability of new concrete, a single size of micro steel straight fibres was selected for the study. Micro steel fibres are straight, with a diameter of 0.3mm, a length of 6mm, and a tensile strength of more than 2,859 MPa. As a result, concrete's tensile and compressive strengths were increased.

All slabs with flexural reinforcement in both directions were made out of 5 mm diameter plain bars with a 6 mm transparent cover on the tension face. It has a yield strength of 469.64 MPa, a tensile strength of 800.7 MPa, and an elongation rate of 6.8%.

Materials	Physical properties	Values				
	Density, Mg/m ³	1.872				
Silica fume	Bulk density, kg/m ³	130-600				
	Specific surface, kg/liter	2.2-2.3				
	Specific surface area m ² /kg	15000-30000				
	Bulk Specific gravity (Surface dry)	2.73				
	Bulk Specific gravity (SSD)	1.6				
Mining sand	Apparent specific gravity	2.66				
•	Absorption, %	3				
	Fineness modulus	1.45				

4.2 Details selection of the flat plate slabs

The specimens depict inner slab-column connections that are simply supported along their four corners, indicating the section of the slab inside the area of negative bending moment and within the lines of contra flexure, that is about equivalent to 0.566% of the distance between columns. The prototype used is a 1:4 scale model of a planned flat plate reinforced concrete slab construction with 5000 mm grid column lines in both directions, column dimensions of 375 mm by 375 mm, and a slab thickness of 200 mm. The current simulated specimen is a square slab with 570 mm c/c spacing between supports in both directions; an overall depth of 40 mm; and a square steel plate with dimensions of (75) mm side length was placed to the middle of the column.

4.3 Experimental parameters

The experimental design for this investigation comprises four simply supported two-way flat UHPFRC slabs, comprising one control sample and three specimens with a drop panel of 10mm, 14mm, and 18mm thickness. Furthermore, all slabs are reinforced with the plain steel bars of 5 mm@40 mmc/c hooked at the ends in both directions, as shown in Figure 1.

4.4 Mix proportion, casting, and curing

The mix proportions used to make flat slabs of UHPFRC accomplish the required strength while preserving good workability and avoiding the balling problem. The water-to-binder ratio is around 0.24, silica fume-to-cement is 0.25, and superplasticizer-to-binder is 0.87%. The volume percentage of straight micro steel fibre is 2%, and the mining sand-to-cement ratio is 0.45.

While the slump flow test was conducted for UHPFRC, the flow table test was utilised to determine the workability for non-fibrous UHPC [14-16]. The average diameter of 640mm was characterized as being within the range of a slump flow test for self-compacting concrete. Finally, it was established that the mix percentage was consistent with the desired outcomes.

The concrete was poured into the mould in two layers using a trowel and a waggon. Each layer was compacted for 30 seconds using the vibrating table. The surface was then leveled using a steel trowel. The concrete was then exposed to the laboratory's temperature and humidity for the next day. Afterward, the specimens were removed from the mould and stored in a steam room at 55 °C for five days. The specimens were then removed from the steam chamber after being wet-cured for the next 23 days.

4.5 Strain measurement for steel bars

During the loading test, the electical strain gauges are utilized to monitor reinforcement strain. It is connected to the reinforcement bars in a single direction at distances of half, twice and fourth times the effective depth of slab from the face of the column.

4.6 Strain at compression face of the specimens

The location and direction of LVDTs on surface of the specimens was prepared by drawing three lines at 0° , 45° , and 135° at one of the slab corners, with the intersections located 300 mm from the supports. The, three LVDTs were fixed to the prepared compression face using super glue M200 to form a strain rosette method.



Figure 1: Details of the flat slab specimens

4.7 Test setup

Four 50mm x 75mm rectangular sections with a height of 50mm were welded together to form a robust frame with a 25mm diameter and a clean circular surface. On two sides of the frame's top, fixed and welded steel bars functioned as pin supports, while free steel bars acted as roller supports. The universal testing machine is located at the structural laboratory of the University of Sulaimani's was used in this work to test slab specimens for punching at a varied test speed, as shown in Figure 2.

4.8 Testing procedure

Before taking the first strain gauge and instrument data, the slabs were placed horizontally, the load was gently applied on the centre of the specimen using the bearing head column piston at a rate of 0.05 MPa/sec. At each load, all the parameters were recorded, and fractures were identified. The load which produce the initial crack's was indicated. When failure was reached, the load was recorded, and loading was ceased when a decrease in load reading matched with a rise in LVDT reading. Four full HD digital cameras were employed to record each specimen's hole testing operation.

5 RESULTS AND DISCUSSION

This investigation, the main parameters was studied while testing the reinforced concrete specimens for punching shear to represent the effect of different thickness of drop panel. In addition, the drop panels were covering the critical section for punching shear , which was around %10.5% of the total slab area.



Figure 2: Loading setup

5.1 **Properties of UHPFRC concrete**

Based on the test findings, the mechanical parameters of UHPFRC were determined: cylinder compressive strength of 150.67 MPa, split tensile strength of 10.53 MPa, flexural strength of 12.69 MPa, and modulus of elasticity of 48.72 GPa.

5.2 The effect of the thickness of the drop panel

In this section examines how the thickness of the drop panel affects the punching shear resistance of UHPFRC simply supported two-way flat slab specimens:

5.2.1 Punching shear resistance at the first crack and ultimate loads

Figure 3 depicts the impact of drop panel thickness grew from 10mm to 18mm (from 25% to 45% of total slab depth), which loads owing to an increase in punching shear resisting area. Furthermore, when compared to the control sample (S20CO), the sample with a thickness of 18mm (45% of the slab's entire depth) had the strongest resistance up to 40% at the first fracture load and 48 percent at the ultimate stress.

5.2.2 Deflection of flat slabs at point load (patch load)

Figure 4 shows how the thickness of the drop panel influences the deflection values at point loads for flat slabs with varying drop panel thicknesses (0, 10, 14, and 18 mm). The value of deflections at ultimate loads for flat slabs with thick drop panels increases by up to 30% due to the resistance to extra load until failure is caused by a boost in flat slab stiffness.



Figure 3: Punching shear capacity of flat specimens at the crack and ultimate loads





Table 7 shows how drop panel depth affects concrete surface strain at cracks and ultimate loads in flat slabs. The increase in drop panels from 10mm to 18mm reduced strain on concrete surfaces due to the rigidity of flat slabs under steady load, as compared to the control sample. Furthermore, samples with an 18mm drop panel thickness increased the strain value at the concrete surface by 600% and 3160% at the fracture and ultimate loads, respectively.

5.2.4 Strain in steel reinforcement bars

Table 7 summaries the influence of drop panel depth on strain in steel bars at the peak loads in flat slabs at the different distances from the column face. At the yield point, the reinforcement's strain was 7.2×10^{-3} mm/mm. It was determined that all steel reinforcing slabs yielded at various locations. Furthermore, the sample with an 18mm drop thickness enhanced the strain value in reinforcing bars by up to 74%. The punching shear resistance at the ultimate load increased the thickness of drop panels from 10mm to 18mm in reinforcement bars.

5.2.5 Rotation angle at support

Table 7 demonstrates the correlation between the depth of the drop panel and the rotation angle of the support at the first crack and peak loads for flat slabs. Furthermore, since flat slabs are rigid due to increasing their stiffness, the rotation may be enhanced by up to 385%.

5.2.6 **Crack patterns and modes of failure**

Table 2 illustrates the effect of drop panel on the angle of inclination between tension and compression faces at ultimate loads, as well as the impact of drop panel thickness on fracture pattern and modes of failure (Figures 5 and 6). Additionally, the impact of drop panel thickness on the details of cracks is illustrated in Table 2. On the basis of these results, it is possible to conclude that the inclination angle of a sample drop panel with a depth of 18 mm will increase by as much as 1.01%.

Samples code	Aspect ratio	Ultimate load (KN) Crack load (KN)	Ultimate load (K	Strain at the concrete surface at crack load mm/mm *10^-3	Strain at the concrete surface at ultimate load mm/mm *10^-3	The strain of steel bars from the face of the col- umn (patch load) (mm/mm×10-3)		Rotation of crack load (Rotation of ultimate load	Inclination angle (D	Number of crac	
			N)			at 0.5d	at 2d	at 4d	adial ×10- ³)	(radial ×10 ⁻³)	egree)	Ś
S20CO.	-20	25.00	40.89	0.10	0.31	12.68	11.98	11.41	5.23	12.21	74.48	12.00
S20Z20D10		30.00	56.07	0.64	2.77	17.38	16.43	15.64	6.98	45.36	75.14	18.00
S20Z20D14		35.00	57.18	0.49	2.68	17.73	16.75	15.95	6.98	34.89	62.29	21.00
S20Z20D18		35.00	60.49	0.60	0.98	18.75	17.72	16.88	6.98	47.10	75.30	25.00

 Table 2: Shear strain at concrete surface, strain in the steel bars, rotation angle at support and inclination angle with number of cracks in flat slabs



Figure 5: Crack pattern for flat slabs without drop panel.



Figure 6: Crack pattern for flat slabs with different thicknesses of the drop panel.

6 CONCLUSIONS

The findings of an investigation into how the thickness of the drop panel affects punching shear have been evaluated. Here are some potential deductions or conclusions:

1. The thickness of the drop panel enhanced the capacity of flat slabs for punching shear by up to 40% at the first crack load and 48% at the ultimate load.

2. Due to increasing thickness of drop panels, the values of deflection, shear strain at the concrete surface, strain in steel bars, flat slabs' rotations at supports, and crack inclination angles between concrete tension and compression faces were enhanced up to 30%, 316, 74%, and 385 percent, respectively, at ultimate load, which increased the stiffness of flat slabs.

REFERENCES

- P. Olmati, J. Sagaseta, D. Cormie, and A. J. E. S. Jones, "Simplified reliability analysis of punching in reinforced concrete flat slab buildings under accidental actions," vol. 130, pp. 83-98, 2017.
- [2] K. Pilakoutas and X. J. J. o. S. E. Li, "Alternative shear reinforcement for reinforced concrete flat slabs," vol. 129, no. 9, pp. 1164-1172, 2003.

- [3] A. Committee, "Building code requirements for structural concrete (ACI 318-05) and commentary (ACI 318R-05)," 2005: American Concrete Institute.
- [4] A. S. Genikomsou and M. A. J. A. S. J. Polak, "Effect of openings on punching shear strength of reinforced concrete slabs-finite element investigation," vol. 114, no. 5, p. 1249, 2017.
- [5] A. C. Thakur, R. John, and K. SCOE, "USE OF FLAT SLABS IN MULTI-STOREY COMMERCIAL BUILDING."
- [6] H. Yin, "Structural Behaviour of Composite RC Members Strengthened with UHPC Subjected to Static and Dynamic Loading," 北海道大学, 2018.
- [7] J. Liao, K. Y. Yang, J.-J. Zeng, W.-M. Quach, Y.-Y. Ye, and L. J. E. S. Zhang, "Compressive behavior of FRP-confined L. Moreillon, J. Nseir, and R. J. P. o. H. Suter, "Shear and flexural strength of thin UHPC slabs," pp. 748-756, 2012.
- [8] T. N. Nguyen, T. T. Nguyen, and W. J. E. S. Pansuk, "Experimental study of the punching shear behavior of high-performance steel fiber reinforced concrete slabs considering casting directions," vol. 131, pp. 564-573, 2017.
- [9] P. Lampropoulos, J. N. Duncan, and O. T. Tsioulou, "Punching shear resistance of UHPFRC," vol. 114, pp. 867-872, 2019.
- [10] [10] M. E. Shoukry, A. M. Tarabia, A. M. J. P. o. t. I. o. C. E.-S. Yassin, and Buildings, "Punching shear strength of ultra-high-performance fiber concrete slab–column connections," pp. 1-13, 2021.
- [11] X. Yan, Y. Gao, Y. Luo, Y. Bi, and Y. Xie, "Effect of different steel fiber types on mechanical properties of ultra-high performance concrete," in IOP Conference Series: Materials Science and Engineering, 2021, vol. 1167, no. 1, p. 012001: IOP Publishing.
- [12] J. L. Dalton et al., "Properties of Portland cement made from contaminated sediments," vol. 41, no. 3, pp. 227- 241, 2004.
- [13] R. T. Thorstensen, P. J. M. Fidjestol, and Structures, "Inconsistencies in the pozzolanic strength activity index (SAI) for silica fume according to EN and ASTM," vol. 48, no. 12, pp. 3979-3990, 2015.
- [14] ASTM-C1611/C1611M. (2009b). Standard Test Method for Slump Flow of self-Consolidating Concrete. Annual book of ASTM standard, C1611/C1611M,4.02, 859-864.
- [15] ASTM-C230/C230M. (2003). Standard Specification for Flow Table for Use in Tests of hydraulic Cement. Annual book of ASTM standard, C230/C230M, 4.01, 206-211.
- [16] F. R. Karim, B. H. Abu Bakar, C. Kok Keong, and O. Q. Aziz, "Review on behaviour of underreinforced shallow fibrous concrete solid beams under pure torsion," International Journal of current Advanced Research, vol. 6(7), pp. 4924-4932, 2017.