CONSTRUCTION
e-ISSN: 2785-8731
VOL. 2, ISSUE 1, 55 – 65
DOI: https://doi.org/10.15282/cons.v2i1.7581

UNIVERSITI MALAYSIA PAHANG

ORIGINAL ARTICLE

The Influence of Drop Panel's Dimensions on the Punching Shear Resistance in Ultra-High-Performance Fiber-Reinforced Concrete Flat Slabs

T. A. Muhammed[1] and F.R. Karim[2]

[1]M.Sc. student, Civil Engineering Department, College of Engineering, University of Sulaimani, Sulaimani, Kurdistan Region, Iraq.
[2]Lecturer, Civil Engineering Department, College of Engineering, University of Sulaimani, Sulaimani, Kurdistan Region, Iraq.

ABSTRACT – Ultra-high performance fiber reinforced concrete (UHPFRC) is a high-performance cementitious material with enhanced tension, compression, and toughness, strengths in the post crack region with high ductility, toughness, and durability. The companies prefer to use it to construct highly durable structures such as high-rise buildings, towers, and bridges. In addition, the thickness of the flat slab produced by UHPFRC might be thinner than the conventional concrete. One problem that has always been a concern in a flat slab is the punching shear failure since this failure is brittle and occurs suddenly without any previous notice. Besides, the position of the critical section for punching shear could be changed based on the thickness of the drop panel and the inclusion of fiber in the concrete. This paper highlights the effect of drop panels dimension on the punching shear resistance in UHPFRC flat slabs. The four two-way interior UHPFRC supported flat slab panels, consisting of one control flat slab without drop panels and three-flat slabs with different sizes of drop panels (10.5%,14.5%, and 19%) of the total area of slab drop panels, tested under punching load. Results indicated that the covered area of flat slabs by drop panel around 10.5% improved punching load up to %20 and 37% at the crack and ultimate loads. Furthermore, the test results show that the efficient covered area for resisting punching was 10.5% of the total area of the tested slab. Besides, the deflection values, strain in reinforcement and concrete, rotation at supports, and the inclination angles of cracks were improved due to the stiffness enhancement in the flat slabs.

ARTICLE HISTORY
Received: 31st Mar 2022
Revised: 04th Apr 2022
Accepted: 13th Apr 2022

KEYWORDS
Drop panels
Flat slabs
Punching shear resistance
UHPFRC

INTRODUCTION

Reinforced concrete flat slabs are defined as a slab that carries the columns without any beams. Flat slabs are widely used in multi-story buildings such as office buildings, residential buildings, hotels, hospitals, and car parks due to flexibility in room layout, shorter construction time, building height savings, and ease of installing mechanical and electrical services. Flat slabs have some weak points, and the significant disadvantages such as restricting mechanical ducting and deflection at the middle strip may be critical [1,2].

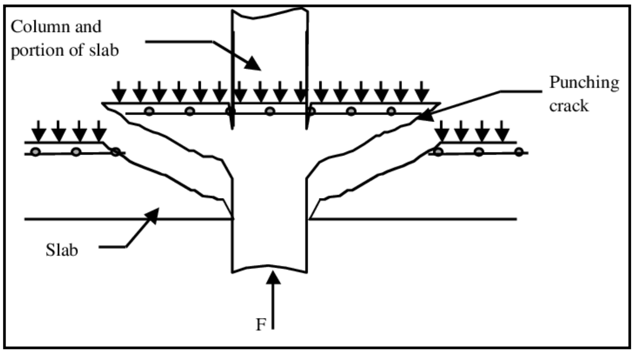
One problem that has always been a concern in a flat slab is the punching shear failure since this failure is brittle and occurs suddenly without any previous notice. Punching shear is a local failure case that occurs due to the collection of local stresses within the closeness of the supporting column. Although the punching shear capacity of reinforced concrete flat plates can be increased by various means, their applicability is often limited; for example, traditional shear reinforcing using stirrups applies only to slabs with a depth greater than 150 mm [3]. Besides this type of structure, when exposed to lateral seismic loads, shear stresses in the slab increase due to an unbalanced moment, and a crack occurs within the slab in the nearness of the column. The cracks develop through the thickness of the slab at various angular degrees to the bottom of the slab, which leads to punching shear failure of the slab along with the crack propagation [4].

Thus, the drop panels with appropriate thickness are active in decreasing the shearing stresses where the column is liable to punch through the slab, also provide an enhanced moment of resistance where the negative moments are highest and stiffen the slab and decrease deflection. The slab may be in the column area of the same depth, or it may be thickened as a drop panel. The column may also be of the constant section, or it may be changed to form a column head or capital. For cases where spans are large and load particularly heavy, both the drop panel and column head may be used [4]. The critical section of punching shear is assumed to locate at a distance d/2 from the face of the column. Besides, if the drop is provided in a flat slab system, then the d/2 distance is considered from the face of the column [5].

MECHANISM OF PUNCHING SHEAR FAILURE IN FLAT REINFORCED CONCRETE SLABS

The mechanism of punching shear failure in a flat slab occurs if the flat slab is gradually exposed to increase the loading. The first crack will appear at the tension face of the slab around the column due to a negative moment close to the column. On extra loading, if the structure is not strong enough in shear, a truncated pyramid of concrete will be pushed out of the slab [14], as determined in Figure 3.

*CORRESPONDING AUTHOR | F.R. Karim | ferhad.karim@univsul.edu.iq

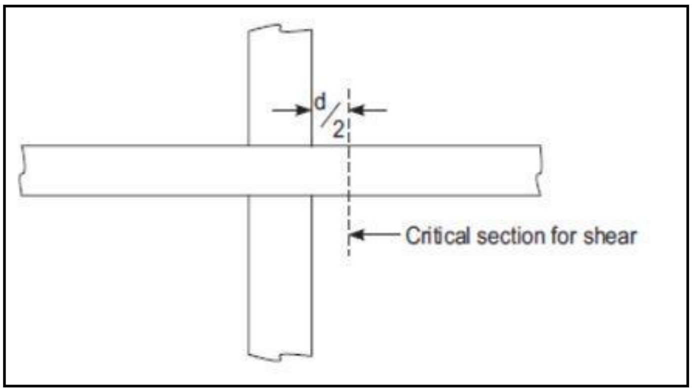


F: Resistance force from the column

Figure 3. Mechanism of punching shear failure in the reinforced concrete flat slab [14].

CRITICAL SECTION FOR PUNCHING SHEAR IN FLAT SLABS WITHOUT DROP PANEL

The critical section of punching shear is assumed to locate at a distance d/2 from the face of the column based on the maximum shear stress at this location, as illustrated in Figure1 [14].



*d: effective depth of flat slabs.

Figure 1. The critical section of the flat slab without a drop panel for punching shear [14].

CRITICAL SECTION FOR PUNCHING SHEAR IN FLAT SLABS WITH DROP PANEL

Flat slabs are widely used in multi-story buildings such as office buildings, residential buildings, hotels, hospitals and car parks. For cases where spans are large and loads particularly heavy, the drop panel must be used. The drop panels with appropriate thickness are active in decreasing the shearing stresses where the column is liable to punch through the slab, also provide an enhanced moment of resistance where the negative moments are highest and stiffen the slab and hence decrease deflection. [15]. Besides, if the drop is provided in a flat slab system, then d/2 distance is considered from face of the drop of the column, as shown in Figure 2.

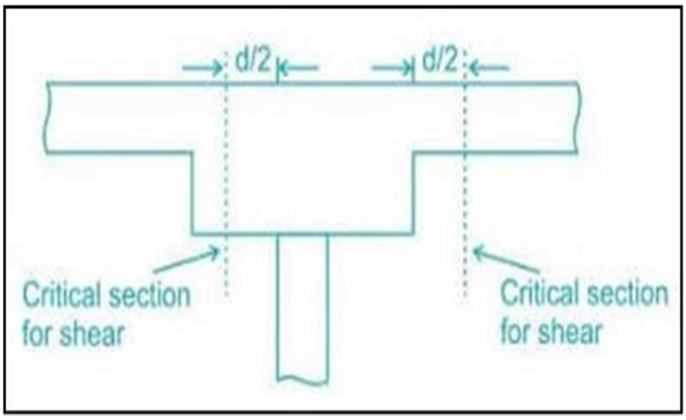


Figure 2. The critical section of a flat slab with a drop panel for punching shear [14].

LITERATURE REVIEW

ULTRA-HIGH-PERFORMANCE FIBER REINFORCED CONCRETE

Ultra-high-performance concrete is also known as Reactive Powder Concrete (RPC). It is a high-strength material produced by Portland cement, silica fume, fine silica sand, high-range water reducer, and water. By adding steel or organic fibers to its ingredient and becoming ultra-high performance fiber reinforced concrete (UHPFRC), which is distinguished by a high-performance cementitious material with enhanced strength in tension, that means greater capacity to deform and support flexural and tensile loads, even after initial cracking, also possibility to eliminating steel reinforcement in some application, also very high compressive strength from 150 to 200 MPa without heat curing, allow the designer to use smaller element section, resulting in the use of less material, to yield at the same capacity. Therefore, UHPFRC is used in structures with a protective nature, such as non-penetrable coverings and structural element parts that must be strong against hostile environments and severe loadings such as earthquakes, effects, or blasts. UHPC has superior flowability, that means can be sprayed in very dense reinforcement and finished with a smooth surface; in addition, characterized by fast strength development, strengthening individual intact members by local- or complete filling, and both wet and dry methods are possible. UHPC, due to these properties, has more applications such as tall buildings, towers, bridges, scraper paths in treatment plants, narrow supports, thin or slab-like components, buttresses for high pressures, repair and strengthening of structure [6].

PUNCHING SHEAR RESISTANCE IN UHPFRC FLAT SLABS

The behavior and strength of ultra-high-performance concrete flat slabs incorporating fiber for punching shear resistance without drop panels are discussed in the following section. Besides, it contains some background on the current punching shear strength requirements and how to improve the punching shear resistance at peak load.

Moreillon et al. [7] presented an experimental program on thin UHPC slabs with and without conventional steel reinforcement. The goal with one normal strength concrete sample and six UHPC tests was to analyze the interaction between the thickness of slabs, the reinforcement ratio, and the volume fraction of fiber in the serviceability limit state and ultimate limit state. The six UHPC tests have highlighted the good contribution of UHPC combined with steel reinforcement bars on flexural and shear capacity. They also found that increasing fiber content tends to decrease the strain capacity at ultimate load by locating the plastic strains of the rebars on a single macro-crack.

Nguyen et al. [8] tested eight high-performance steel fiber reinforced concrete (HPFRC) slabs to study the effect of fiber orientation on the punching shear strength. Three flat slabs were cast and provided a two-volume fraction of steel fiber. The results showed that the volume fraction of steel fiber and the casting position of the tested slabs remarkably influenced the size of the failure cone of the punching shear failure.

Lampropoulos et al. [9] highlighted the punching shear resistance by changing the slab thickness. Tested fifteen simply supported UHPC slabs up to failure for all slabs included steel fibers except three slabs. The test results presented that the adding of steel fibers significantly enhanced the load capacity of the slabs.

Shoukey et al. [10] tested ten simply supported UHPFC slabs up to failure to obtain their punching shear strength by varying the compressive strength from 56 to 123 MPa, and the volume fraction of fibers were 0%, 1%, 2%, and 3%. Besides fiber shape (end-hooked or corrugated) was used, and fiber size with the same aspect ratio, fiber type and material (polypropylene or steel or fiberglass) was also used. Using steel fibers of hooked-ended type with larger length and diameter improved the punching shear strength, but it did not affect the first flexural cracks.

Yan et al. [11] studied twelve simply supported UHPFC slabs by varying volume of fraction from 0 to 4%. up to failure tested to show mechanical properties of UHPFC. The effect of steel fiber on the UHPC mechanical properties of UHPC was measured. The investigational outcomes showed that the inclusion of steel fiber influenced the operating performance of UHPC, and the slump and expansion degree of UHPC was inversely proportional to the volume fraction of fibers and aspect ratio of steel fiber. The steel fiber notably enhanced the compressive and flexural strength of UHPC. UHPC showed a gradual decrease of compressive strength and a gradual increase of flexural strength with the increase of aspect ratio of steel fiber on the condition of constant volume content of steel fiber.

RESEARCH OBJECTIVES

Punching shear is one of the problems in the reinforced concrete flat slabs in the interior, exterior, and edge slab-column connections. The sheer capacity of slab-column connection could be improved by high strength in concrete, particularly in UHPC. This research attempted to study punching shear resistance at the crack and ultimate loads by providing drop panels with constant thickness and aspect ratio 20 of micro steel cooper coated fiber in UHPFRC flat slabs, which changes the positions of the critical section for punching shear. The main objective of this research could evaluate the influence of the area covered by the drop panel on the punching shear resistance in the interior UHPFRC flat slab column connection.

EXPERIMENTAL PROGRAM

This section contains the experimental work in detail and the preparation of ultra-high-performance fiber-reinforced concrete specimens, and the properties of materials used in this research. Details of the specimen's configuration and preparation of four UHPFRC flat slabs are also discussed. A total of ten 620mm×620 mm UHPFRC flat slab specimens were cast and tested to prove the effects of the covered area of drop panels on the punching shear capacity. This study was used ultra-high-performance fiber-reinforced concrete that contains cement, mining sand, silica fume, superplasticizer, and copper coated micro steel fiber.

Selection of materials

Materials used in this research for creating ultra-high performance fiber reinforced concrete for the target strength above 150 MPa are explained in the following paragraphs:

The best selected Portland cement for preparing UHPFRC is very important. The type of cement used in this study was Tasluja Ordinary Portland Cement type I, from TCC Company. The physical properties are complied with [12].

The silica fume was used in this investigation is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. The main field of application is as pozzolanic material for high-performance concrete. The physical and chemical properties of silica fume are shown in Tables 1 and 2.

This study used mining sand with a bulk specific gravity of 1.6, percent of absorption of 3%, and fineness modulus of 1.45. Gradation of fine aggregate is illustrated in Table 3 and complied with ASTM C33 standard specification [13]

Tap water is used for mixing materials and producing UHPFRC. It was clean and free from oil, organic material, and other deleterious substance.

For the ultra-high performance concrete mix, High Flow PCE 120 type F was used in this study to provide workable concrete with low water to binder ratio (w/b).

The straight type of copper-coated micro steel fiber was used in the investigation to produce UHPFRC slabs with a volume fraction of 2%. One size of micro steel fibers is chosen for use in the investigation to avoid dry balling of fibers and reduce workability for fresh concrete. Therefore, the tensile and compressive strengths of concrete were improved. The properties of micro steel fibers are tabulated in Table 4.

The flexural reinforcement of all slabs was provided in both directions consisting of plain bars 5mm in diameter placed at the tension face with a clear cover of 6 mm. The properties of the steel reinforcement are illustrated in Table 5.

Table 1. Physical properties of silica fume.

Physical properties	Values
Density, Mg/m^3	1.872
Bulk density, kg/m^3	130-600
Specific surface, kg/liter	2.2-2.3
Specific surface area m^2/kg	15000-30000

Table 2. Chemical properties of silica fume.

$\%SiO_2$	$\%Al_2O_3$	$\%Fe_2O_3$	%CaO	$\%Na_2O$	$\%K_2O$
98.41	0.2	0.89	0.028	0.03	0.022

Table 3. Mining Sand Properties.

Sieve Size, mm	Passing %	ASTM C33 limits, %	
		Lower	Upper
1.18	100	95	100
0.6	89.69	80	100
0.3	70.67	50	85
0.15	50.45	25	60
0.07	29.64	5	30
pan	0	0	0
Bulk Specific gravity (Surface dry)		2.73	
Bulk Specific gravity (SSD)		1.6	
Apparent specific gravity		2.66	
Absorption, %		3	
Fineness modulus		1.45	

Table 4. Properties of straight copper-coated micro steel fiber.

Properties	Micro steel fiber
Diameter, mm	0.3
Length, mm	6
Aspect ratio, λ	20
Shape	Straight
Tensile strength (MPa)	≥ 2859

Table 5. Tensile test of the reinforcement steel bar.

Properties	Diameter, mm	Area mm^2	Yield strength, MPa	Ultimate strength, MPa	Elongation%
Value	4.9	18.86	469.44	800.73	6.8

Selection of flat plate slab and prototype of the specimens

The prototype selected for this research can be considered one-fourth scale of a designed flat plate concrete slab structure with similar grid column lines of 5000 mm in both directions, the column dimension was 370mm×370 mm, and the thickness of the slab is 200 mm. The specimens represent interior slab-column connections supported along its four edges, representing that portion of the slab within the negative bending moment region, inside the lines of contra flexure, which is approximately equal to 0.566 times the span between columns, as shown in Figure 4. The present simulated specimen produced in this case after scaling is a square slab with spacing between supports 570 mm c/c in both directions, a total thickness was 40 mm, and loaded by square bearing steel plate with dimensions (75×75) mm, which was applied at the center of the column.

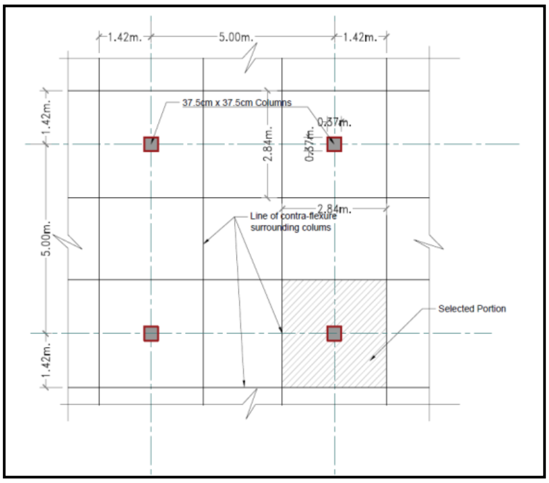


Figure 4. Prototype of flat plate slab system and selected specimen.

Experimental parameters

The experimental plan of this research contains four UHPFRC supported two-way flat slabs, which include one control samples (without a drop panel), and three specimens with a drop panel, that have an aspect ratio of fiber equal to 20 and the same thickness of drop panel 10mm. The details of the panels are shown in Table 6. All slabs are reinforced with fifteen plain steel bars of Ø5 mm@40mmc/c and hooked at the end of steel bars in both directions, equivalent to a steel reinforcement ratio of 1.4%. Moreover, 6 mm cover, as shown in Figure 5.

Table 6. Characteristics of slabs with drop panels.

Parameter*	Notations	Cover area by drop panel concerning the total area of slab, %
Control slab without drop panel	(S20CO)	0
Dimension cover by drop panels 200x200mm	(S20Z20D10)	10.5
Dimension cover by drop panels 230x230mm	(S20Z23D10)	14.5
Dimension cover by drop panels 260x260mm	(S20Z26D10)	19

S: aspect ratio of steel fibers, Z: side length of drop panel, cm, D: the thickness of drop panel, mm, CO: control sample

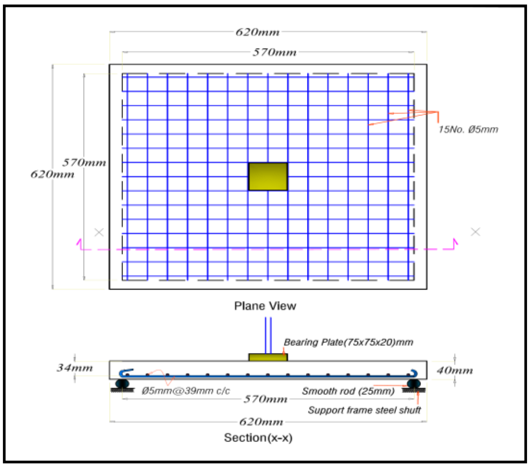


Figure 5. Slab specimen dimensions and the details of reinforcement.

Mix proportion, casting, and curing

The mix proportions for ultra-high-performance fiber-reinforced concrete flat slabs, to achieve target strength with high workability and avoid balling phenomenon, the following mix proportions were adopted as shown in Table 7.

Flow table test (ASTM-C230/C230M, 2003) was used to obtain the required workability for non-fibrous ultra-high-performance concrete, while slump flow test (ASTM- C1611/C1611M, 2009b) was carried out for ultra-high performance fiber reinforced concrete. It was found that the mix proportion, in the end, is compatible with the targets.

Table 7. Mix proportions for ultra-high performance fiber reinforced concrete.

Concrete type	w/b	Cement	Silica fume	Plasticizer	Mining sand	The volume fraction of steel fiber
UHPFRC	0.24	1	0.25	0.0187	0.45	2%

Casting was carried out by placing the concrete mixture into the slab's mold using a trowel and a cart. The concrete mixture was placed in the mold in two layers. Then, each layer was vibrated for 30 seconds using the vibrating table. The vibration was applied to all layers, and the top layer was vibrated until the number of bubbles was reduced, and a steel trowel leveled the surface. After that, the concrete was kept in the laboratory temperature and humidity for 24±2 hours. Then, the specimens were removed after 24 hours from the mold and placed in the steam chamber for five days under moisture steam at 55 °C. Then the UHPFRC slabs were removed from the steam chamber wet cured with burlap for 28 days.

Strain measurement for steel bars

Electrical metal-foil sensing grid strain gauges used for measuring strain occur in the reinforcements during the loading test. It is fixed on the top surface of the reinforcement bars in one direction at distances 0.5d, 2d, and 1.5d from the face of column location, where d is the effective depth of slab specimens, as shown in Figure 6.

Strain at compression face of concrete flat slabs

The compression surface of slab specimens was prepared by drawing three lines at 0º, 45º, and 135º degrees at one of the slab corners, which intersection between lines positioned at 300 mm from support. The areas on the drawn lines were ground with sandpaper and cleaned with a gauze sponge. Then, the three LVDT with 50 mm displacement measurement capacity was bonded to the prepared compression face by M200 superglue to make a strain rosette and denoting LVDT1, LVDT2, and LVDT3 to measure the slab concrete surface strain occurred due to compression during loading test.

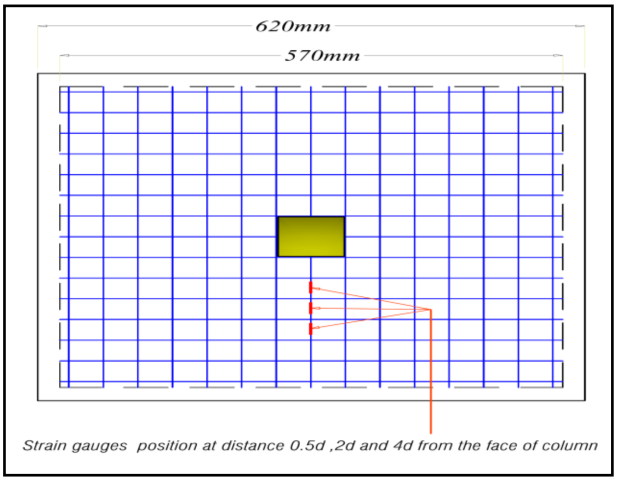


Figure 6. Strain gauges positions from the face of the column.

Test setup

Supports were constructed special as a simple support, consisting of four rectangular sections 50mm x 75mm with 50mm height, welded together to form the strong frame and smooth circular 25mm diameter. Steel bars at the top of the frame were fixed and welded on two sides to serve as pin supports and free on the other two sides hinged to serve as roller support. The testing machine is available in the structural laboratory in the civil engineering department at the University of Sulaiman. Its serial number 50-C1400/FR was used in this study with a capacity of 150 kN (15 tons) to test the specimens for compression, flexure, and punching of slab panels with a required variable speed is shown in Figure 7.

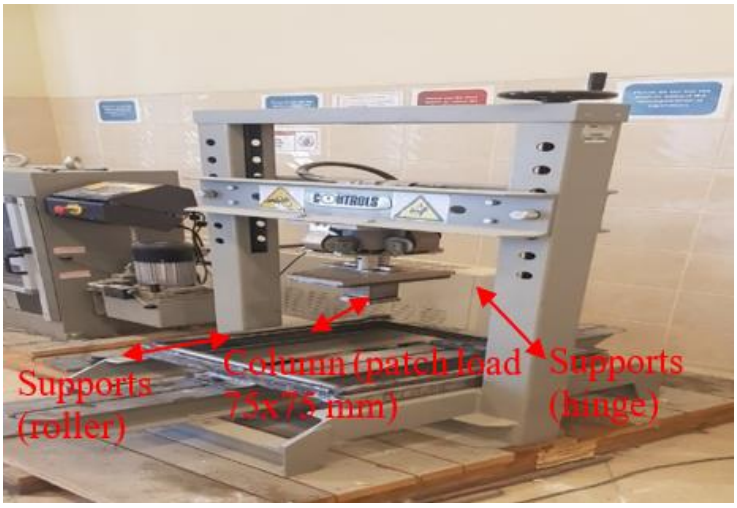


Figure 7. Testing machine with supporting frame.

Testing procedure

The slabs were placed horizontally and centered on the supports, then the first readings of strain gauges and instruments were recorded. The load was applied slowly through the bearing head column with a 0.05 MPa/sec speed rate. At each loading stage, the deflection at the center of the slabs, rotation at the supports, LVDT's measurement of concrete strain on the compression face, and strains of reinforced steel bars were recorded, and a search was done for the appearance of any cracks. The positions and extents of the first crack were visible, and other consequent cracks were marked. When the failure was achieved, the load was recorded, and the loading was stopped at the moment where load reading showed a drop and was associated with increasing LVDT reading. The hole testing process of each specimen was recorded through the four full HD digital camera.

RESULTS AND DISCUSSIONS

This research investigates the behavior and strength of ultra-high-performance reinforced flat concrete slabs incorporated micro steel fiber for punching shear to represent two-way interior UHPFRC simply supported flat slab for the same aspect ratio of fiber (L/D=20) constant thickness of drop panel (10mm) and different covering critical section for punching shear of the flat slab by drop panel.

Properties of UHPFRC concrete

The mechanical properties of UHPFRC were determined based on the test result, as shown in Table 8.

Table 8. Mechanical properties of UHPFRC concrete at 28days age.

Cylinder compressive strength, MPa	Split tensile strength, MPa	Flexural strength, MPa	Modulus of elasticity, GPa
150.67	10.53	12.69	48.72

The effect of covering the critical section of slabs by drop panel on the punching shear resistance

This section explains the effect of the covered area of the slab by drop panel on punching shear resistance in the flat slab, which contains 4 UHPFRC supported two-way flat slab specimens, including a control sample.

Punching resistance of flat slabs at the crack and ultimate loads

The influence of covered area, including the critical section for punching shear by drop panel on the punching shear at the crack and ultimate loads for reinforced UHPFRC slabs including fiber with an aspect ratio of 20 and thickness of drop panel 10mm in specimens, as shown in Figure 8. There can be noticed that the sample S20Z20D10 with a covered area by drop 34375mm^2 has increased crack load by 20% and also by 37 % at ultimate punching load if it compared to the control sample (S20CO). It was recorded that by increasing 10.5% of the covered area by drop, the crack and ultimate load were improved due to the enhancement of resistance for punching shear and changing the position of the critical section for punching for (d) beyond the dimension of drop panel.

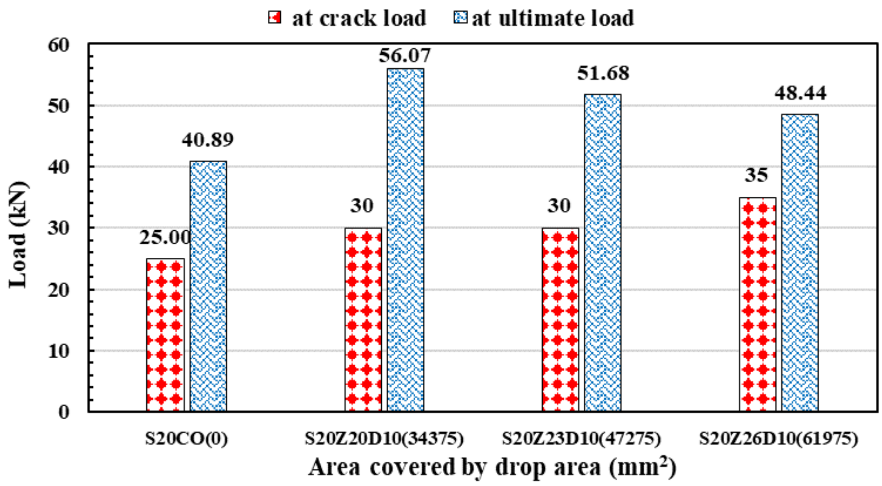


Figure 8. Crack and ultimate loads of flat slabs under punching with different areas of drop panels.

Deflection of flat slabs at point load (patch load)

This section described the effect of the covered area by drop on the deflection of flat slabs at point load, which contains 4UHPFRC supported two-way flat slab specimens with the same thickness of drop panel and different areas covered by drop panel. The influence of covered area by drop on the deflection at point load of flat slabs for specimens is shown in Figure 9. Besides, there can be noticed that increasing the covered area of drop by %10.5 recorded the highest resistance by 37% at ultimate load, with a maximum deflection of 9.6 % if it compared to the control sample. It was observed that improvement of the covered area by %10.5, the deflection at mid-span was decreased at ultimate load due to enhancement of the flat slab for punching shear from moving critical section out of this area, also due to the improvement of stiffness of flat slabs.

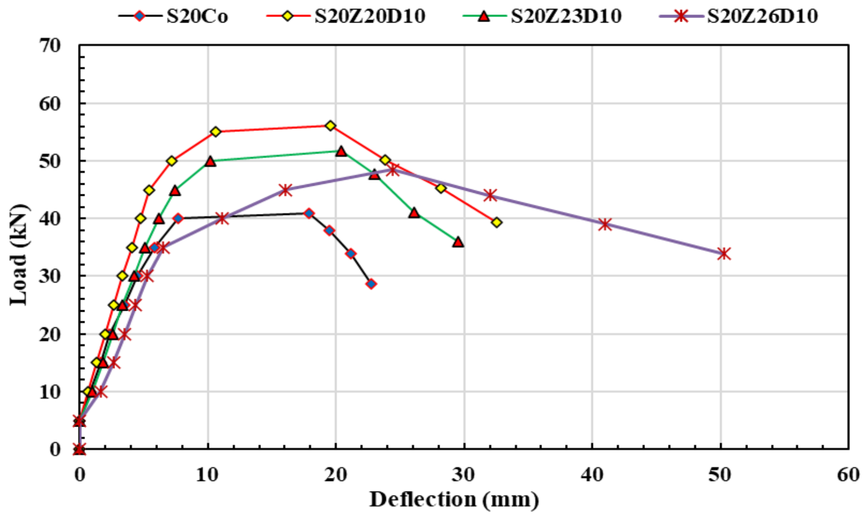


Figure 9. Load versus deflection at point load in flat slabs with drop panel.

Shear strain at the concrete surface

The influence of covered area by drop panel on the shear strain at the concrete surface at the crack and ultimate loads for flat slabs with a constant depth of drop panel and aspect ratio 20 is illustrated in Table 9. It was noticed that with the development of the covered area by drop from zero to %10, the shear strain at the concrete surface was increased in the crack and ultimate load due to the increased covered area by drop panel and resisting punching shear capacity. Besides, there can be observed that a flat slab covered the critical section by drop panel and covering by %10.5 of slab surface area S20Z20D10 has the highest resistance by 37 % at ultimate load, with the value of shear strain at concrete surface greater by nine times if it compared to the control sample (S20CO).

Table 9. Shear strain at the concrete surface in flat slab with drop panel under punching at the crack and ultimate loads.

Samples code	Strain in the concrete surface at crack load mm/mm *10^-3	Strain in the concrete surface at Ultimate load mm/mm *10^-3
S20CO.	0.10	0.31
S20Z20D10	0.64	2.77
S20Z23D10	0.41	1.85
S20Z26D10	0.34	2.83

Strain in reinforcement bars

The effect of the covered area by drop panel on the strain in reinforcement bars at ultimate loads for samples at a distance of 0.5 d, 2 d, and 4 d distance from the face of the column is tabulated in Table 10. The value of strain reinforcement bars was equal to 7.2×10-3 mm/mm, at the yield point while 68× 10-3 mm/mm at the ultimate point. It was noted that steel reinforcement in all slabs was yielded but did not exceed the ultimate limit. The results indicated that the maximum strain was recorded at a distance of 0.5 d, and the minimum strain was noticed at a distance of 4d from the face of the column for all models. It was noticed that the development of the covered area by drop from zero to %10.5, the strain in reinforcement bars was increased due to increasing the stiffness of flat slabs and the enhancement of the bond strength between steel bars and the matrix of the concrete.

Table 10. Strain in the reinforcement in the flat slab at different positions from the face of the column.

Samples code	Strain from the face of the column at ultimate load		
	at 0.5d (mm/mm×10^{-3})	at 2d (mm/mm×10^{-3})	at 4d (mm/mm×10^{-3})
S20CO	12.68	11.98	11.41
S20Z20D10	17.38	16.43	15.64
S20Z23D10	16.02	15.14	14.42
S20Z26D10	15.02	14.19	13.51

Rotation angle at support

The influence of covered area by drop panel on the rotation angle at support at the crack and ultimate loads for samples is illustrated in Table 11. The result recorded that rotation angle at concrete support for samples increased covered area of drop panels by %10.5 (S20Z20D10) have maximum ultimate load by 37% with the value of rotation angle at support by 371% greater than control specimen S20CO. It was noticed that the development of the covered area by drop from zero to %19, the rotation angle at support was improved due to the improvement of stiffness of flat slabs.

Table 11. Rotation angle at the support of flat slabs with drop panel at the crack and ultimate loads.

Samples code	Support rotation	
	at crack load (radial $\times 10^{-3}$)	at ultimate load (radial $\times 10^{-3}$)
S20CO	5.23	12.21
S20Z20D10	6.98	45.36
S20Z23D10	6.98	31.40
S20Z26D10	6.98	31.40

Crack patterns and modes of failure

The effect of the covered area by drop panel on the angle of inclination at ultimate loads for samples is shown in Table 12. Besides, the influence of covered area by drop on crack pattern and modes of failure is illustrated in Figure 7. The result can be observed that for sample (S20Z20D10) that covers the area by 10.5% has resistance by 37 % at ultimate load, with the value of inclination angle greater by 0.9 % compared to the control sample (S20CO). It was noticed that the development of the covered area by drop from zero to %19; the inclination angle was improved due to the improvement of flat slabs stiffness.

Table 12. The inclination angle of crack for a flat slab with drop panel under punching load.

Samples code	Number of cracks	Inclination The angle of cracks, degree
S20CO	12	74.14
S20Z20D10	24	75.48
S20Z23D10	19	75.56
S20Z26D10	18	75.80

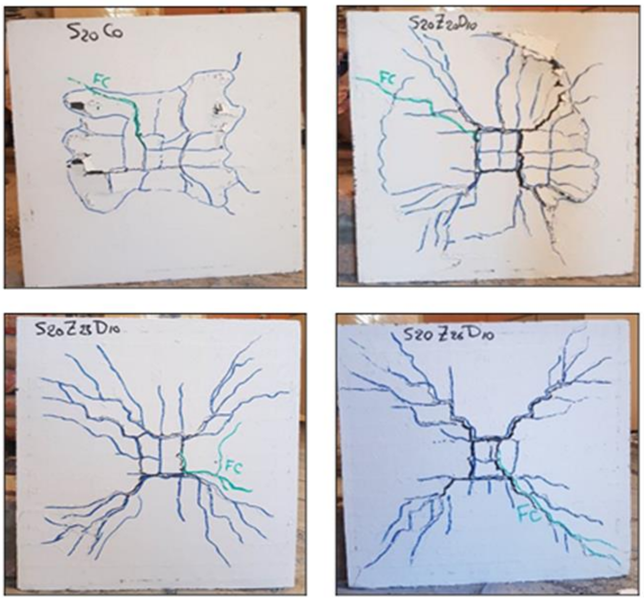


Figure 10. The crack pattern of tension face in flat UHPFRC slabs with drop panel.

CONCLUSIONS

An experimental study on the effect of drop panels with the different areas covered the critical section of punching shear was concluded. The following conclusions could be drawn:

1. It was found that covered area of flat slabs by drop panel around 10.5%, the punching shear resistance improved up to %20 and 37% at the crack and ultimate loads.
2. The test results show that the efficient covered area for resisting punching was 10.5% of the total area of the

tested slab.

3. The deflection values, strain in reinforcement and concrete, rotation at supports, and the inclination angles of cracks were improved due to stiffness enhancement in flat slabs.

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