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A Mini-Review on the Structural Behavior of Reactive Powder Concrete Reinforced Slabs

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Abstract

Two-way slabs are widely used members in constructions due to the huge necessity for them because it has the property of carrying loads for the columns, piles, and even the soil. In order to extend the two-way slabs for larger spans, designers need to maximize the slab thickness, which will increase the structure's self-weight, which may not be able to resist. So, designers treated such a problem by increasing the overall concrete strength of slabs in order to prevent the choice of increasing the slab thickness. This article reviewed the previous studies to summarize some significant points, such as the effect of using steel fibers and openings within slabs was also investigated, as well as the use of reactive powder concrete. It was concluded that the severity of openings in slabs depends on their location, shape, and size. In some cases, larger openings might behave structurally like separate beam systems, but it often still reduce capacity significantly. Also, the ultimate load was decreased by increasing the opening size with the same CFRP (Carbon-fiber reinforced polymer) reinforcement ratio. Furthermore, the method of strengthening with CFRP is more effective than the method of using Steel fibers (SF).

Keywords: *Reactive powder concrete, two-way slabs, bending and shear capacity, reinforced concrete.*

1. Introduction

Reinforced concrete slabs (RCS) are commonly used parts in constructions and are widely used for multiple-story buildings [1]. Usually, the slab was built to resist the vertically applied dead and live loads [1]. Slabs are usually considered as structural members which has a small depth compared to their other dimensions [1]. Slabs could be supported by two opposite sides, which introduced a simpler behavior for the slab and is named a one-way slab due to its primary deflection in one direction, as shown in Fig.1 [3]. While the slab of fourth sides supporting and its length equals less than twice the width, it deflects in two directions, and the applied load on the slab transfers to all the supporting sides. This slab is called a way slab (TWS) as shown in Fig.1. [2].

TWS is an economical and popular construction system that consists of a plate of uniform thickness cast with the beams or directly on columns [3]. Slabs have been used in different applications such as floors, roofs, walls of the buildings, and as bridge decks. Slabs may extend in one or two directions, rest on steel or concrete beams, brick or shear wall, or directly on the structure’s columns [4]. In order to achieve some of the architectural or structural requirements, like large spans, the height of the slab has to be raised to avoid large deflections [5]. Still, by doing so, the slabs get more and more self-weight and need a larger number of columns, stronger columns, and a foundation to overcome the unexpected loads or additional self-weight. Thus, the construction will consume more material, which is uneconomic, to reduce the possible large spans[5]. So, one of the solutions to minimize the increase in slab self-weight is the use of RPC (Reactive powder concrete). By which a reduction in the dimensions of the structural member will enhance its high resistance [5].

The study surveying the literature articles which involves steel fibered two way slabs, reactive powder concrete, silica Fume concrete in order to collect the best knowledge of about how does these parameters effect on the two-way slab behavior.

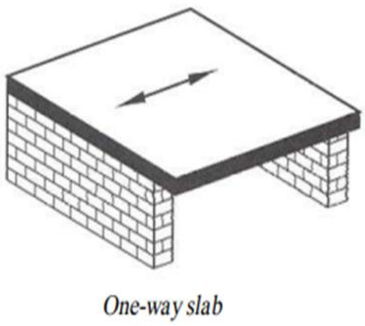

Fig. 1. One-way and TWS [3]

1.1. Reactive Powder Concrete (RPC)

RPC is a modern technology in concrete, developed in France in 1990, and used for the first time in constructions in 1997 for the Sherbrooke footbridge [6], as explained in Fig. 2. It is a material with ultra-high strength, advanced Mechanical Properties (MP), and high ductility composite material. It generally consists of Steel Fibers (SF), silica-fume superplasticizer, cement, very fine sand (0.15 - 0.6 mm), replacing ordinary aggregate, and hydrated with a very low water amount (low water-cement ratio (w/c)) [6]. Because of the replacement between the gravel and the fine sand, the cement content of the RPC is as high as 900-1000 Kg/m^3 [6]. So, one of the essential positive characteristics of this type of concrete is that it can exhibit significant tensile strength and toughness.

RPC governs an important requirement in many applications, such as the need to bridge large spans, high-pressure pipes, and is also suitable for impermeable or hazardous fluids or nuclear wastes [7]. Moreover, it is utilized in any construction that requires extra safety and security, such as blast-resistant or any other expected dynamic loads. Furthermore, it is a good option for structures that need lightweight and thin components, like the roofs for Stadiums [7].

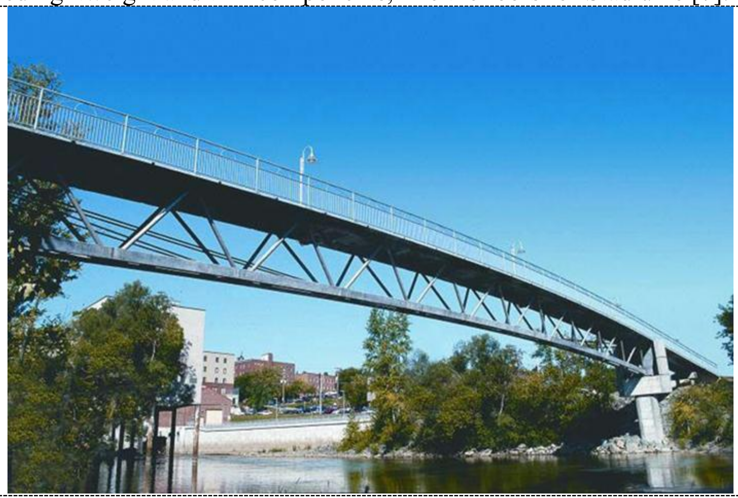

Fig. 2. Sherbrooke footbridge [8]

"The RPC concept is based on the principle that material with a minimum defect, such as microcracks and interval voids, will possess greater load-carrying capacity and greater durability" [9]. It is possible to get by following the next concepts [10]:

1- Reducing gravel makes the material more homogeneous and develops it by replacing as many coarse aggregates as possible with dried ingredients of similar particle size.
2- To raise the mix unit weight, a granular size distribution must be used.
3- Using heat curing to enhance the microstructure chemical reactions.
4- Utilizing SF in order to enhance ductility, tension, splitting, and rupture strengths.
5- Adding superplasticizer for the fresh concrete in order to minimize the water-cement ratio and enhance the workability.
6- Exposing stresses to the molds before and during setting to expel excess water.

Some applications of RPC are shown in Fig.3.

Fig. 3. Applications of RPC [11]

1.2. Slab with Opening

Opened Concrete slabs are usually utilized and designed in accordance with the building codes requirements, which introduces limitations in accordance with the opening size and the magnitude of stress. In spite of a lack of sufficient information about the load-carrying capacity of the slab with an opening [12].

Electrical and mechanical services like fire protection pipes, heating, plumbing, electrical wiring, telephone, computer network, water supply, sewerage, and ventilation are the main reasons for using openings in slabs. Lifts, stairwells, and elevator shafts all require a substantial-sized opening cause of the structure's capacity to disperse stresses; the structural impact of tiny apertures is typically ignored. However, because concrete and steel reinforcement are cut out jointly, it can rarely reduce the strength and load-bearing capability in the case of significant slab holes. As a result, constructions may be less able to withstand the applied loads and the structural requirements. [13].

The design of RCS with an opening is not clearly indicated in the B.S 8110, 1997 [14]. Anyway, the ACI-318, 2014 [15] shows the openings allowed in the new slab system. The ACI code provides guidelines for various opening locations in reinforced concrete flat plates and slabs. The apertures' dimensions and locations are depicted in Fig.4. The ACI code permits openings of any size in the vicinity of the middle strip intersection. The size of the aperture allowed in the space where two column strips overlap is 1/8 the width of the column strip. The maximum size permitted in the region where one middle strip and one column strip overlap is just 1/4 of the width of the middle or column strip in either span direction. In order to adhere to ACI 318 criteria, the total number of reinforcements for a slab without openings in both directions must be maintained. Therefore, it is necessary to rebuild the interrupted reinforcement on both sides of the holes. [15].

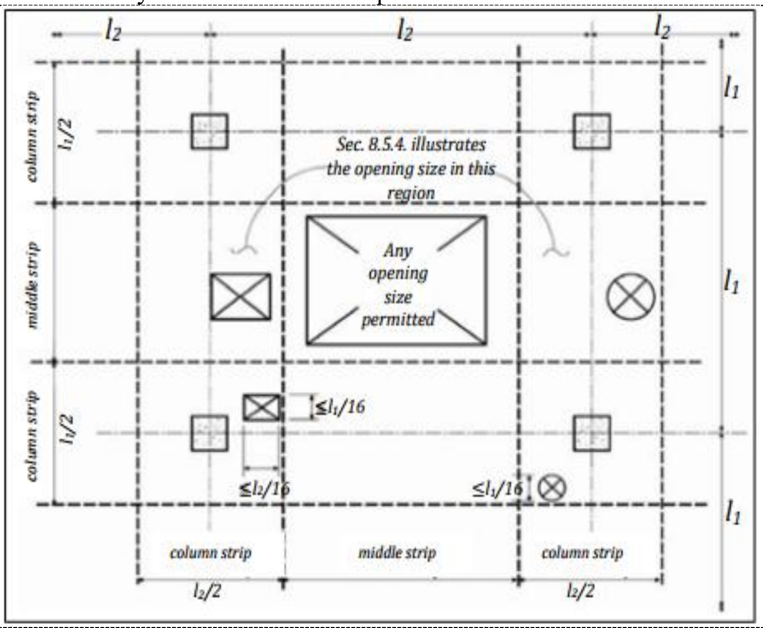

Fig.4. Opening size and locations according to ACI-318, 2014 [10]

2. Literature review

RPC is the outcome of concrete technological development. It is a novel kind of composite material that provides better ductility and workability while meeting the growing needs for high strength and durability [16].

High-performance characteristics of RPC, a cementitious material, include reduced creep and shrinkage, low permeability, ultra-high strength, and enhanced corrosion resistance. Cause of its unique qualities, RPC is a material that is revolutionizing concrete technology and may be used in a variety of structural and non-structural applications [17].

2.1. Development and MP of RPC

The first production of RPC is the return of Richard and Cheyrezy [18] in 1994. Two types of RPC were advanced with compressive strength (f'c) equal to 200 MPa and 800 MPa [18].

In 2012, Hassan [19] studied the punching shear behavior of slabs made of ordinary and modified RPC. The experimental side included casting and testing twenty specimens with dimensions (1000*1000*50 or 70) mm. These specimens included four variables, which are SF ratio, bending steel amount, slab thickness, and concrete type, in order to find out the impact of these variables on the punching shear strength of simply supported slabs made of RPC and MRPC under point load at the slab center. The experimental part also included the effect of SF ratio and lack of coarse aggregates on some MP, like f'c, splitting tensile strength, modulus of elasticity, and modulus of rupture. The laboratory results showed that the increased fiber content improved the MP of RPC. It was also found that the punching shear failure occurs suddenly in slabs that do not contain SF, where there is no warning before failure except for the rapid motion of the dial gauge. Generally, the ultimate load increases with an increase in slab thickness, steel reinforcement ratio, and steel fiber content.

In 2014, Kadhum [20] studied the performance of RPC slabs with varying heat of curing conditions, which were 25°C and 90°C. The experimental study was conducted to determine the influence of adding SF and heat treatment on slabs made of RPC. Twelve specimens were cast and tested with dimensions (560*560*20, 40 or 60) mm. All the specimens are simply supported and loaded by a square plate with dimensions (70*70*25) mm. In this study, the variables, SF ratio, thickness of slab, and curing type were studied. The percentage of (silica fume) SiF used in this study was 25%. The test results showed that increasing the SF ratio and using heat treatment led to improved f'c, splitting tensile strength, modulus of rupture, and modulus of elasticity, as well as their positive influence on flexural strength. The f'c at 28 days ranged between 163 and 194 MPa for the non-heat- and heat-treated specimens. The results also showed that the increase in the thickness led to an increase in the ultimate load.

The enhancement in the slabs' total capacity, which were of depths 20,40, and 60 mm, was 16,12, and 13 % respectively when compared with the non-heat-treated slab specimens, when SF is used at 2% by volume. It was also discovered that, when the slabs get thicker, the displacement is minimized. Table 1 shows the results of this study.

Table 1. Sample of the results of testing RPC slabs [20]

Slab	The magnitude of load at the First crack (kN)	Failure load (kN)	Middle span displacement at first crack (mm)	Middle span Deflection at failure load (mm)	Mode of failure
RPC 1-20/N	42.2	79.0	2.6	9.1	Flexural
RPC 1-40/N	45.8	94.6	2.1	6.9	
RPC 1-60/N	47.7	109.2	1.5	4.2	
PRC -2-20/N	43.0	89.6	4.4	13.6	
PRC 2-40/N	76.2	103.5	3.8	11.4	
PRC 2-60/N	85.3	114.0	2.5	8.9	
PRC 1-20/H	49.8	93.2	3.0	10.2	
PRC 1-40/H	53.0	101.0	2.5	7.8	
PRC 1-60/H	54.8	117.3	1.8	5.3	
PRC 2-20/H	50.1	105.3	5.1	14.6	
PRC 2-40/H	86.0	117.0	4.6	12.1	
PRC 2-60/H	97.2	128.4	2.9	10.3	

In 2014, AL-Hassani et al [21] investigated the MP of RPC with various SF and SiF content. This study included three variables, which were neatly investigated: SiF content (SF 0%, 10%, 15%, 20%, 25%, 30%), SF volume fraction (VF 0%, 1%, 2%, 3%), and a type of superplasticizer. The experimentally tested specimens showed that the increase in volume fraction of SF from 0% to 1%, 2%, 3% caused an increase in the f'c of the cube by 3.72%, 8.36%, and 8.89% respectively. In comparison, the cylinder f'c was increased by 6.36%, 9.9%, and 11.54% consecutively. The increase in SiF content from 0% to 10%, 15%, 20%, 25%, and 30% led to increasing the f'c of cube by 13.54%, 18.02%, 24.72%, 29.86%, and 34.17% consecutively, as well as increasing the f'c 17.56%, 20.30%, 30.92%, 33.79%, and 41.04% consecutively. The direct tensile strength increased by 59.4%, 145.05%, and 238.35%, the splitting tensile strength by 90.88%, 186.51%, and 258.45%, and the flexural tensile strength by 52.62%, 166.61%, and 217.27% in that order when the SF volume fraction increased from 0% to 1.0%, 0%, and 3.0%. Increasing the SiF concentration and SF volume fraction improved the stiffness behavior, which in turn increased RPC's ductility and fracture toughness.

In 2017, Hiremath et al [22] Cement, sand, SiF, steel fiber, and quartz powder with a low water to binder ratio were the materials used in this study on MP of RPC under various curing conditions has better qualities like greater strength, durability, and long-term stability due to their thick microstructure, with a flexural strength of 75 MPa and a f'c of 800 MPa was recently created. [15]. Four types of curing were used in this study: hot air curing(HC) at 100C°, steam curing(SC) at 90C°, normal curing(NC), and air curing(AC). In comparison to normal curing and air curing, the experimentally evaluated specimens demonstrated superior performance when cured under hot air and steam curing. Test findings demonstrate that, out of the three hot air curing periods, two days at 100˚C produce better outcomes than one day. Three days after, the strength development percentage at 100˚C after two days of hot air curing is 4.29% higher than that after one day and 5.27% higher than that after three days or all curing regimens, the curing time was maintained at 24 hours, the f'c test was performed on cubes of 100*100*100 mm.

In 2015, Qaseem [23] conducted an experimental study on the punching shear behavior of square and trapezoidal shape slabs made of RPC. The work involved testing six slabs divided into two series, each series consists of three specimens which have the same shape but different in SF content (0, 0.5, and 1) % of the total volume. The dimensions of square specimens were (0.45*0.450*0.05)m, while the trapezoidal shape specimens' dimensions were (0.450m width of lower side, 0.620m length, 0.05m thickness, and 0.2m the width of the upper side). All slabs were simply supported and under a point load (which was a square plate of 0.4 m side length) at the center of the slab—according to test results, punching shear strength increases by roughly 62.5% and 100% in square slabs and 8.3% and 41.7% in trapezoidal slabs that include 0.5% and 1% of SF, respectively, when the fiber concentration increasables 2 and 3 include the test results.

Table 2. Test result of square specimens [23]

Slab Designation	f_{cu} MPa	Loading (kN)		Deflection (mm) at		Failure Mode
		First Crack F.C.L	Ultimate U.L	First Crack	Ultimate Load	
S0.0	85	16	50	77	170	Punching Shear
S0.5	101	18	66	31	155	
S1.0	115	22	83	26	143	

Table 3. Test results of trapezoidal specimens [23]

Slab Designation	**f_{cu} MPa**	**Loading (kN)**		**Deflection (mm) at**		**Failure Mode**
		First Crack F.C.L	ultimate U.L	First Crack	ultimate Load	
T0.0	85	15	60	80	143	Punching Shear
T0.5	101	17	65	26	139	
T1.0	115	22.5	87.5	21	155	

In 2016, Abid [24] studied the behavior of cambered RPC slabs under impact loads. The variables studied in this study were the effect of slab cambering, thickness of slab, SF ratio, steel strip stiffeners, and ordinary steel reinforcement. The experimental results revealed that a cambered RPC slab has an enhanced capacity compared with other stiffened slabs, despite the fact that the impulse of force was the greatest amongst all models. Furthermore, it was concluded that by raising the cambering up to 2cm, permanent displacement and crack width were minimized by about 65%, 86%, 67% respectively. Ultrasonic Pulse Velocity (UPV) test revealed that cambering of (1cm) minimized the ability to see crack width but increased the number of invisible cracks. In contrast, a cambered slab (2cm) has reduced both visible crack width and the number of invisible cracks.

In 2017, Abdulrahman et al [25] studied the effect of different curing conditions on the MP of RPC. The research involved an experimental investigation to determine the different curing conditions on MP of RPC, such as f'c influence on the splitting tensile strength and modulus of rupture. Until 28 days, three different methods of curing were employed: immersion in water at 35° C (the reference-curing scenario), immersion in water at 90° C for five hours every day, and immersion in hot steam for five hours every d dditionally, this study examines how adding SiF as a proportion of cement weight affects RPC MP at three distinct percentage ratios (5, 10, and 15%). The test findings indicated that, for all SiF percentages, the inundation approach in hot water at 90°C is the most effective curing method (in terms of improving the RPC MP).

Adheem [26] studied the MP and structural behavior of the RPC member under repeated loads. After investigations, it was concluded that the addition of SF to RPC caused an improvement in the f'c. Adding SF of 0.5% and 1% volume fraction leads to maximizing the f'c by 10.8% and 30.02% respectively, when comparing with RPC without SF. The results also showed that the increase in SiF content from 15% to 25% leads to an increase in the f'c by only 6.88% and 11.61% which is less effective compared with the addition of steel fiber. Additionally, it can be inferred that increasing the SF ratio from 0% to 0.5% and 1% causes the splitting tensile strength to rise to 35.2% and 77.18%, while increasing the SiF percentage from 15% to 20% and 25% causes the splitting tensile strength to rise to 2.38% and 11.83%, respectively. The experimental studies also showed that, in comparison to nonfibrous RPC, the addition of 0.5% and 1% volume fraction of SF increases the modulus of rupture by 49.88% and 96.41%, respectiv y iF, however, has minimal impact on the modulus of rupture, the modulus of rupture rises to 7.59% and 16.15% in succession when the SiF ratio rises from 15% to 20% and 25%, when the SF volumetric increases from 0% to 0.5% successively, the modulus of elasticity rises to 42.35GPa and 45.44GPa, representing increases of 5.56% and 13.26%, while increasing the percentage of SiF from 15% to 20% and 25% results in increases of 0.8% and 3.58% for the modulus of elasticity.

2.2. Structural Behavior of Slabs

In 2003, Limam et al. [27] studied the reinforced concrete TWS strengthened with CFRP (Carbon-fiber reinforced polymer) strips. The experimental work is the first section of this study, which includes the testing of two reinforced concrete slabs with dimensions (1700*1300*70) mm. The first slab was strengthened with (CFRP) strips externally, which bonded to the tensile face, and the other slabs were not strengthened as a control slab. The second section of this study deals with a limit analysis model. The experimental investigations finally introduced that bonding the CFRP strips externally strengthened the two-way RC slabs significantly.

In 2006, Rochdi et al. [28] made a comparison between a theoretical and an experimental investigation to determine the punching shear strength of two_way concrete slabs externally bonded by CFRP composite sheets. First, the punching failure behaviour as well as the parameters controlling this mode of failure were investigated, and an analytical model for the punching failure of RCS was presented. According to the findings, the slab's ultimate punching shear strength increased as the composite section area increased. Additionally, all reinforced slab displacements were significantly less than those of the control slab; the punching load increased between 67% and 177% above the control slab, and the average deflection of the reinforced specimens at the maximum load was around 0.28 times that of the reference specimens. This model, which is based on numerical simulation, enables slab treatment while taking into account the steel reinforcement's dowel effect contribution. It is necessary to take into account the biaxial behavior of composite sheets arising from TWS boundary conditions in order to generalize this model to the situation of slabs externally joined by CFRP. The ultimate punching shear strength of eight slabs with varying degrees of CFRP reinforcement that are intended to fail in shear was finally predicted using the theoretical results showed a good agreement between the experimental and anticipated values, according to the results.

In 2007, Enochsson et al. [29] presented a computational and experimental study for CFRP-strengthened apertures in two-way concrete slabs. In this investigation, an evenly distributed load was applied to eleven slab CFRP sheets, which were used to reinforce six opening slabs, which were subsequently contrasted with traditional steel-reinforced slabs. The slabs were square, measuring 2600 mm on each side and 100 mm in thickness. Openings of two distinct sizes—850 * 850 mm and 1200 mm squared are utilized. It was determined that the design method's need for steel reinforcement because of an aperture provides a safe load-bearing capacity. Additionally, compared to the samples with smaller apertures, the specimen with larger openings showed a stiffer load versus deflection behavior and a much greater collapse load, which contradicts the recommended design methodology. Perhaps it's because the slabs with the large holes behave more like a four-beam system than a slab.

In 2009, Nhabih [30] investigated the response of two_way RCS with an opening strengthened by CFRP. Thirty slabs will be cast and tested as part of the experimental slabs, which were grouped (A, B, C, and D). Group A slabs were the only ones without holes, but Group B slabs had openings in the common junction region of the column strips. Group C slabs have apertures in the common area where the middle strip and column strip intersect. Group D slabs have holes in the common area where the middle strips intersect. The position of openings and the type of strengthening were among the variables examined simply supported conditions, the slabs were put in according to the experimental results, the ultimate load capacity of the strengthened slabs for group A could increase by 42% when compared to the control slabs. In specimen (A-5), the CFRP strip strengthening was perpendicular to the expected crack and parallel to the reinforcing steel bars. When comparing the strengthened slabs for group D to the control slabs, the ultimate load capacity may increase by as much as 41%. The best example is specimen (D-5), which has strengthening parallel to the opening edges and perpendicular to the expected crack that began at the opening corners. Because of abrupt shear failure in these specimens, the findings of strengthened slabs for groups B and C showed a considerable drop in ultimate load capacity, ranging from 2.5 to 25 percent, when compared to the control slab. The behavior of the slab was found to change from ductile to brittle when a CFRP sheet was present on the tension face. Table 4 contains the test results.

Table 4. Collapse load and failure mechanisms for experimentally tested slabs [30]

SPECIMEN	ULTIMATE LOAD (KN/M2)	INCREASE IN ULTIMATE LOAD, %	FAILURE MODE	SPECIMEN	ULTIMATE LOAD (KN/M2)	INCREASE IN ULTIMATE LOAD, %	FAILURE MODE
A-1	55	N.A	Typical flexural failure	B-8	38.5	-3.75	SHEAR
A-2	55.5	0.94	debonding	C-1	46	N.A	SHEAR
A-3	76	38	debonding	C-2	45	-2.5	SHEAR
A-4	75	36	debonding	C-3	35.5	-23	SHEAR
A-5	78	42	debonding	C-4	37	-19.5	SHEAR
A-6	58	5.5	debonding	C-5	35	-24	SHEAR
A-7	59	6.5	debonding	C-6	43.5	-4.5	SHEAR
A-8	77	40	debonding	C-7	43	-6.5	SHEAR

B-1	40	N.A	Shear	D-1	49	N.A	TYPICAL FLEXURAL FAILURE
B-2	39	-2.5	Shear	D-2	49.5	1	DEBONDING
B-3	31	-23	Shear	D-3	67	36	DEBONDING
B-4	32	-20	Shear	D-4	66	35	DEBONDING
B-5	30	-25	Shear	D-5	69	41	DEBONDING
B-6	38	-5	Shear	D-6	51	4	DEBONDING
B-7	37	-7.5	SHEAR	D-7	52	6.8	DEBONDING

In 2010, Makki [3] studied the structural behavior of RCS strengthened by CFRP. Eleven RCS with dimensions (1050*1050*60) mm were tested in this study. According to the testing results, the ultimate loads of the slabs strengthened with bonded CFRP sheets are around 8–64 percent higher than those of the non-strengthened reinforced concrete slab (S dditionally, these reinforced slabs demonstrated less deflection at a similar load than the non-strengthened reinforced concrete slab; the maximum deflection decreased by roughly 4.7% to 7.2% in comparison to the control slab (SC).

In 2011, Abbas [31] carried out research on two-way RC slabs that are simply supported and strengthened with CFRP bars and have square apertures in the middle of the eleven specimens that were cast and evaluated in this study were reinforced with CFRP. At the same time, the other two served as control specimens and were strengthened with conventional reinforcement (steel reinforcement specimens were loaded using a frame made of 950mm long, I-section (120*80) steel members with crossed arms. In order to investigate the impact of opening size on the flexural behavior of RC slabs, all specimens with dimensions of 1050*1050*75 mm and three distinct opening sizes (250*250, 330*330, and 500*500 mm) were used. For each opening's size, there are three specimens with different CFRP reinforcement ratios (over, balanced, and under). The experimental results and details of specimens of this study are listed in Table 5. The test results showed that the ultimate load decreased by increasing the opening size with the same CFRP reinforcement ratio. The results also showed that the ultimate load was increased by increasing the CFRP reinforcement ratio for the same opening size. The ultimate load was increased by 67.21% and 10% when using CFRP reinforcement instead of steel reinforcement for opening sizes (250*250) and (330*330), respectively.

Table 5. Specimen Reinforcement, Opening size, ultimate load, and Maximum deflection [31]

Slab No.	Specimen Rein.	CFRP or Steel Area Af, As (mm^2)	Opening size mm	ultimate load kN	Increasing in cracking load %	Maximum deflection mm
FS1	CFRP	197.82	250*250	102	112.5	10.15
FS2	CFRP	113.04	250*250	87	83.3	8.2
FS3	CFRP	84.78	250*250	60	25	8.02
FS4	CFRP	197.82	330*330	66	37.5	7.95
FS5	CFRP	113.04	330*330	58	20.8	6.8
FS6	CFRP	84.78	330*330	52	8.33	6.38
FS7	CFRP	197.82	500*500	62	29	5.96
FS8	CFRP	113.04	500*500	50	4.2	5.5
FS9	CFRP	84.78	500*500	48	N/A	4.8
SS1	Steel	197.82	250*250	61	27	8.02
SS2	Steel	197.82	330*330	60	25	6.11

In 2012, Muhammed [32] introduced a study on self-compacting RC slabs with opening strengthening of carbon fiber laminated and SF. In this study, eight specimens made of SCC were cast with dimensions (450*450*40)mm divided into two groups, the first cast without SF (self 30), while the second group contained steel fiber (30/s). The specimens S2, SS2, and SC2 have an opening with dimensions (75*75)mm at 75mm from the slab center, and the specimens S3, SS3, and SC3 have an opening with dimensions (75*150)mm at 75 mm from the slab center. Two strengthening methods were used in this study in order to determine the most effective method of strengthening.

The results of the test are shown in Table 6. The results of the test showed that the method of strengthening with CFRP is more effective than the method of using SF. "The use of steel fiber increased the load capacity by 26.67% and 55.7% for small and large openings, respectively, while the use of CFRP increased the load capacity by 46.67% and 55.7% for small and large openings, respectively"[32].

Table 6. Load and deflection characteristics at first crack and ultimate loads of slabs [32]

Slab name	First crack load (F.C.L) (kN)	Ultimate load (U.L) (kN)	$\frac{F.C.L}{U.L}$ %	Deflection at first crack (mm)	Deflection at ultimate Load (mm)
S1	9.5	33	28.7	1.6	4.2
S2	7	30	23.3	2.8	6.5
S3	6.5	30.5	21.3	0.7	4.8
Ss1	11	45.5	18.68	4.5	8.5
Ss2	10	38	26.31	2.7	5.9
Ss3	6	33.5	17.91	2.4	4.6
Sc2	9	44	20.45	1.8	9.4

Sc3	8	47.5	16.84	1.5	5.9

In 2016, Ali [13] studied the behavior of two-way self-compacting concrete slabs that contain square openings in the center under the effect of a uniformly distributed load. The experimental side included casting six SCC slabs with dimensions (650*650*50) mm. One of these specimens was considered to be a control slab, which was cast without opening, in order to compare with the specimens which having openings. Other specimens contain openings with different dimensions (100*100, 150*150, 200*200, 250*250, and 300*300) mm. According to the experimental findings for square slabs with simple support, when the opening ratio (OR) was raised from 0.00% to 25.00%, the cracking and ultimate uniform loads dropped when comparison to the control solid slab, which had opening ratios (OR) of 11.11% and 6.25%, respectively, the maximum percentage reductions in cracking and ultimate loads were 31.82% and 12.1 he percentage drop in ultimate uniform load and cracking load decreased beyond OR=11.11% and 6.25%, respectively.

As a summary, Table 7 collects literature studies taking into consideration the loading type, used materials, and the final conclusions. It could see that, the using of SF enhance the mechanical properties of concrete mix as well as the punching shear capacity because the shear in concrete depence on two parameters which are the compressive strength and the stirrups (noting that, slabs does not have stirrups) so that the whole shear strength will concentrated on the concrete compressive strength, the same enhancement is expacted to obtained after using the CFRP because it supports the slabs at the expected cracking paths and working on collected cracking sides which delays the collapse.

When discussing the bending ability of the slabs, using CFRP beneath the bending zone enhances the flexural capacity as well as adding SF, which has the bridging property, which collects the tites the cracks and transfers the stresses between cracked surfaces.

Table 7. Comparison between the previous results

Study behavior	Reference studied	RPC	CFRP	SF	SiF amount	gains
Punching shear	Hassan [19]	Used	Non.	used	Non.	The presence of steel fibers avoids the punching shear sudden failure and enhances the collapse capacity.
	Qaseem [23]	Used	Non.	Used with SF content (0, 0.5, and 1) %	Non.	Adding Steel fibers and using RPC leads to an enhancement of the punching shear strength of roughly 62.5%.
	Rochdi et al. [28]	Non.	Used	Non.	Non.	The punching load increased between 67% and 177% above the control slab, and the average deflection of the reinforced specimens at the maximum load was around 0.28 times that of the reference specimens.
Statically bending capacity	Kadhum [20]	Used	Non.	Used	25%	The test results showed that increasing the SF ratio and using heat treatment led to improved f'c, splitting tensile strength, modulus of rupture, and modulus of elasticity, as well as their positive influence on flexural strength.
	Enochsson et al. [29]	Non.	Used	Non.	Non.	The design method requires steel reinforcement because an aperture provides a safe load-bearing capacity
	Makki [3]	Non.	Used	Non.	Non.	The ultimate loads of the slabs strengthened with bonded CFRP sheets are around 8–64 percent higher than those of the non-strengthened reinforced concrete slab.
	Abbas [31]	Non.	Used	Non.	Non.	The test results showed that the ultimate load decreased by increasing the opening size with the same CFRP reinforcement ratio. The results also showed that the ultimate load was increased by increasing the CFRP reinforcement ratio for the same opening size.
Impact load	Abid [24]	Used	Non.	Used		The experimental results revealed that a cambered RPC slab has an enhanced capacity compared with other stiffened slabs, despite the fact that the impulse of force was the greatest amongst all models.

3. Conclusions

The effect of using RPC in concrete slabs contains openings were surveying in this study and it was concluded the following:

1. The severity of openings in slabs depends on their location, shape, and size. In some cases, larger openings might behave structurally like separate beam systems, but it often still reduces capacity significantly.
2. The ultimate load was decreased by increasing the opening size with the same CFRP reinforcement ratio.
3. According to [30], CFRP strengthening resulted in higher increases in ultimate load compared to steel fibers, especially in slabs with openings.
4. The behavior of the slab was found to change from ductile to brittle when a CFRP sheet was present on the tension face.

5. The addition of SF to the mixes improved the splitting tensile strength more than the f' dditionally, raising the SF ratio and SiF content raises the modulus of elasticity and rupture.
6. The ultimate punching shear strength of the slab enhanced with a rising composite section area.

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