Effect Of Reinforcement Ratio On Punching Shear Strength Of Reactive Powder Concrete Slab Reinforced With CFRP Bars

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Abstract:

This work is devoted to study the effect of reinforcement ratio (ρ) on punching shear strength of reactive powder concrete slab reinforced with CFRP bars. The experimental program includes investigating the effect reinforcement ratio (ρ) on the first crack, type of failure, load – deflection curve and compression the ultimate punching shear capacity with ACI – 440 equation. All tested slabs were with dimension (1150 × 1150) mm and tested under concentrated load on column at the center of the slab.

تاثير نسبة التسليح على مقاومة القص الثاقب لسقوف المساحيق الفعاله المسلحه بواسطة قضبان الياف الكاربون البوليمريه

الخلاصة

يهتم البحث الحالي بدراسة تاثير نسبة التسليح على مقاومة القص الثاقب لسقوف المساحيق الفعاله المسلحه بواسطة قضبان الياف الكاربون البوليمريه. يتركز البرنامج العملي حول استقصاء تاثير نسبة التسليح على اول شق، نوع الفشل، منحني (الحمل – الهطول) و مقارنة اعلى قيمه لمقاومة القص مع معادله الكود الامريكي (ACI-440). كل النماذج المفحوصه بابعاد (1150×1150) ملم وفحصت تحت حمل مركز على الكولوم بالمنتصف.

1. Introduction

Reinforced concrete slabs may be carried directly by the columns without using beams, drop panels or columns capitals. Such slabs are described as "flat plates".

This type of structures has more space in addition to its pleasant appearance. Flat plates have been widely used due to the reduced construction cost. They are also economical in their formwork and lead to simpler arrangement of flexural reinforcement. An additional advantage of a flat plate is reduced building story heights that result in more usable space in buildings for a given or limited height. Many other advantages can be achieved by flat plates, such as a reduction in dead loads on the columns and foundations [1]. One of the major problems in such structures is the punching shear failure (also known as two-way action shear) that takes place when a plug of concrete is pushed out from the slab immediately above the columns. The pushed plug takes the from of a frustum cone or a cutoff pyramid with a minimum cross section at least as large as the loaded area[2]. Punching shear failure of slabs is usually sudden and leads to progressive failure of flat plate structures; therefore, caution is needed in the design of slabs and attention should be given to avoid the sudden failure condition.

2. Reactive Powder Concrete

Research over the past decade has yielded a new classification of concrete called Reactive Powder Concrete (RPC) now labeled and classified as Ultra-High Performance Concrete (UHPC). UHPC tends to exhibit superior properties such as advanced strength, durability and long-term stability that make it well suited for use in a wide variety of structural and nonstructural applications.[3] The RPC concept is used on the principle that a material with a minimum defect, such as micro cracks and inside voids reveals high resistance and durability. Thus, RPC will possess a greater load carrying capacity and greater durability. This can be possible according to the following concept [4] .

1) Eliminating all the coarse aggregates.

The homogeneity of the concrete material can be improved by eliminating all the coarse aggregates and making, as much as possible the dry components material of the same particle size. All the dry components used in RPC are less than 0.6 mm in particle size.

2) Very low water- cement ratio.

The water cement ratio used in RPC ranges approximately from 0.15 to 0.23. This range of w/c ratio produces not only the highest range of strength, but also ensures that all the water in the mixture will be combined in producing calcium silicate hydrate (CS-H) **[5].**

4) The microsilica or another suitable pozzolanic material.

In RPC materials with high silica content are necessary for optimum performance.

4) Very fine sand.

The largest particles size in RPC are in the aggregate which is the sand (300 – 600m), the next largest particle size is cement (100 m), the smallest particles size are silica fume, which are in the order of (0.1 m) in diameter. The volumes of these particles are selected to achieve the greatest particle packing and hence the greatest density of the paste **[6].**

5) The steel fibers.

They are used in order to increase the concrete ductility and improve its tension, splitting and rupture strength **[7].**

6) Applying the pressure and heat treatment.

They may be helpful to get rid of excess water and to increase the paste density, and can improve chemical process and strength gain.

The above composition and casting lead to the following properties of RPC:

1- Ultra high compressive strength (200-800 MPa) combined with higher shear capacity.

2- Static Young's modulus higher than ordinary concrete and can range from 29 – 74 GPa **[8].**

3- Tensile strength ranging from 20 to 50 MPa, twice as strong as normal concrete in compression **[9].**

4- Fracture energies ranging from 20000 to 40000 J/ **[10].**

5- Flexural strength ranging from 30 to 141 MPa[10].

6- Its low and non-interconnected porosity makes penetration of liquids, gases or radioactive elements nearly nonexistent.

7- Enhanced abrasion resistance provides extended life for bridge decks and industrial floors **[11].**

8- Superior corrosion resistance provides protection from de-icing chemicals and continuous exposition to humid environments **[12].**

3. Carbon-Fiber-Reinforced Polymers (CFRP)

CFRP has become an increasingly notable material used in structural engineering applications over the past two decades. Studied in an academic context, CFRP has proved itself cost-effective in a number of field applications strengthening concrete, masonry, steel, cast iron, and timber structures. Its use in industry can be either for retrofitting to

strengthen an existing structure or as an alternative reinforcing (or prestressing material) instead of steel from the outset of a project. Applied to reinforced concrete structures for flexure, CFRP typically has a large impact on strength, but only a moderate increase in stiffness (perhaps a 10% increase). This is because the material used in this application is typically very strong (3000 MPa ultimate tensile strength, more than 10 times mild steel) but not particularly stiff (150 to 250 GPa, a little less than steel, is typical). As a consequence, only small cross-sectional areas of the material are used. Small areas of very high strength but moderate stiffness material will significantly increase strength, but not stiffness. [12]

CFRP can also be applied to enhance the shear strength of reinforced concrete by wrapping fabrics or fibers around the section to be strengthened. Wrapping around sections (such as bridge or building columns) can also enhance the ductility of the section, greatly increasing the resistance to collapse under earthquake loading. Such 'seismic retrofit' is the major application in earthquake-prone areas, since it is much more economic than alternative methods. [13]

4. Experimental Program

In this work, four reactive powder concrete slabs reinforced with CFRP bars were tested and the flexural reinforcement ratio (ρ_f) is the parameter that study the effect of it on the punching shear capacity and then compared the experimental result with ACI-440 equation for punching shear strength of normal concrete slab reinforced with FRP bars.

4.1 Carbon Fiber Reinforced Polymer (CFRP) Bar

Smooth CFRP imported from china with (θ = 6mm), it allows designers to utilize the greater modulus and tensile strengths of carbon fiber in a non-metallic reinforcing bar

. 4.2 Reactive powder concrete mix design

There are three trial mixes of reactive powder concrete made, according to literature studies of reactive powder concrete. It considered three cylinder (100 x 200) mm as shown in figure (3-5), for each one and tested at 28 day, and the same number of cubic (150 x 150) tested at 7 day, to the average of compressive strength for each trial mix, then the higher one   be considered. Table (1) shown the details of these trial mix.

Table (1): amounts of materials for the trial mixes

Materials	Trials mix 1	Trials mix 2	Trials mix 3
Cement (Kg)	740	768	800
Silica fume (Kg)	180	192	200
Fine sand (Kg)	1012	1140	1100
Superplasticizer(Kg)	30	40	48
Water (Kg)	220	144	210
Steel fiber (kg)	118	157	157

The trial mix 2 was considered which, it gave the maximum average compressive strength (108 Mpa) as show in table (3-2).

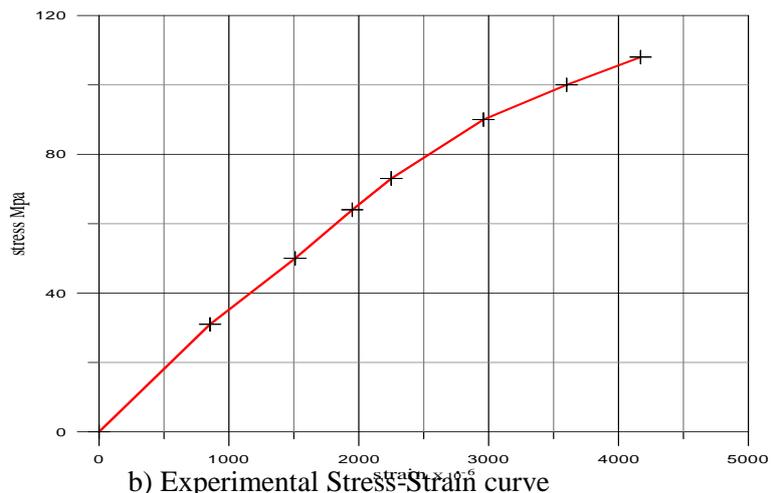Table (2): The compressive strength of each trial mix at 28 days

Tested at 28 days	Trial mix 1			Trial mix 2			Trial mix 3		
Compressive strength (mpa)	100.23	104.25	103.63	107.67	109.34	107.05	109.88	107.45	104.2
Average	102.7			108.02			107.17		

4.2.1 Compressive stress-strain curve

Three of the cylindrical specimens that were tested in compression were previously instrumented with strain gauges, (two strain gauges for each cylindrical specimen); see Fig.(1-a). This configuration allowed to register the ascending branch of the stress-strain curve, as well as the concrete strain corresponding to the compressive strength. The stress-strain curves for the average of three cylinders are shown in Fig.(1-b).

a) 2 strain gauges for tested cylinder   b) Experimental Stress-Strain curve

Fig. (1): Compressive stress-strain curve

4.2.2 Tensile strength

In this work, the concrete tensile strength was determined by splitting tensile tests on cylindrical specimens and by the flexural tensile strength of prismatic specimens. The equipment used to perform these tests was a universal ELE Machine model with a capacity of 2000 kN. The average results of three specimens was adopted for each test and reaching 14 MPa in this work. The modulus of rupture of the average three tested specimens reached 18.4 MPa.

4.2.3 Specimens Description

A total of fourt RPC square two-way slabs were cast and cured under laboratory conditions, the specimens were designed to study the punching shear response of RPC two-way slabs reinforced by CFRP bars and the details of slabs shown in table (3). All of the tested slabs were of the same lateral dimensions (1150×1150) mm and column dimension (c=150mm) as figure (2).

Table (3): The details of specimens

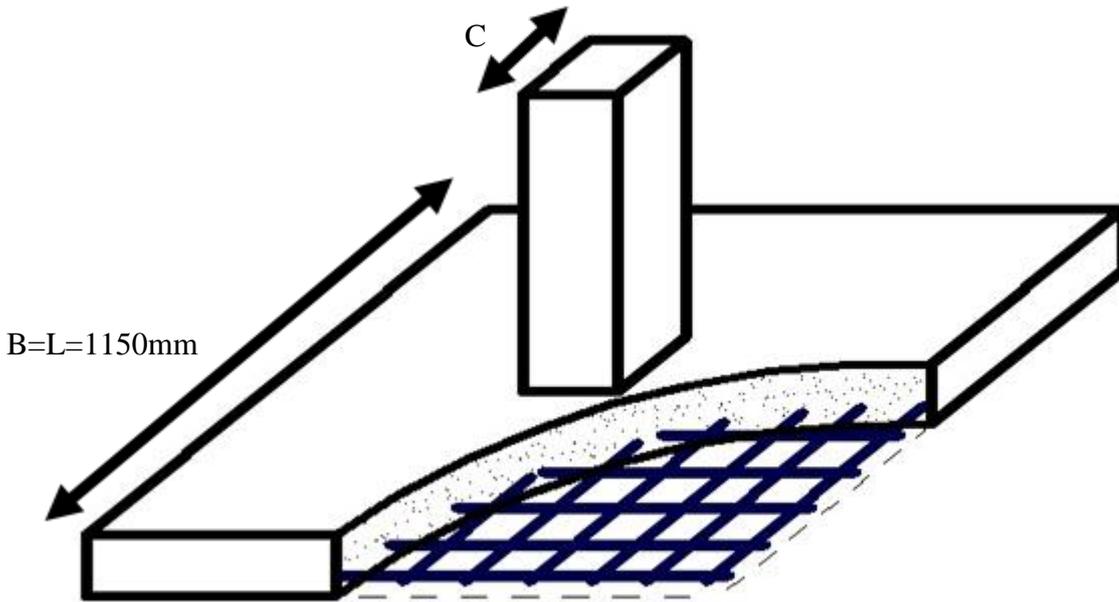| Slab	CFRP ratio %	Thickness of slab h (mm)	Column C(mm)	No. of bars in each direction	Arrangement reinforcement
S – 1	0.3686	100	150	12	One mesh
S – 2	0.3993	100	150	13	One mesh
S – 3	0.43	100	150	14	One mesh
S – 4	0.4607	100	150	15	One mesh

C

B=L=1150mm

Fig (2): section of slab specimen

5.Result and discussion

5.1 General Behavior of Slabs Under Loading

The general behavior (crack pattern and failure mechanism) of (4) slabs are all nearly identical, When the load is applied to the slab specimen, the first visible crack (bending cracks) is observed at the tension face of the tested slab at load level equal to (32.21 – 34.28)% of ultimate load as shown in Table (4). In all slabs, cracking on the tensile face began near the center and radiated towards the edges (semi- random phenomena). As the load is increased the cracking migrates to the opposite face. At higher loads, the already formed cracks get widened while new cracks started to form. The new formed cracks are roughly circular or elliptical in shape and occurred in the tension surface of the slab. Failure of the slab occurred when the cone of failure radiating outward from the point of load application pushed up through the slab body (brittle failure with limited warning). At failure, the slab is no longer capable of taking additional load. No cracks are observed in the

compression face of any slab, except those which are initiated around the loaded area at failure, which are almost the same as that of the loading column dimensions.

Table (4): crack load and ultimate experimental load

Slabs	Column Dimensions C (mm)	Thickness Of Slabs (mm)h	CFRP Ratio %	Ultimate Experimental load (P_u.) kN	First Crack load ($P_{cr.}$) kN	$P_{cr.}/P_u$ %
S – 1	150	100	0.3686	140	45	32.21
S - 2	150	100	0.3993	165	55	33.34
S – 3	150	100	0.43	170	58	34.12
S – 4	150	100	0.4607	175	60	34.28

5.2 Effect of CFRP Reinforcement Ratio

Table (5) shows the effect of reinforcement ratio on the ultimate resistance of the slabs when all the other variables remain constant. It is clear that increasing the reinforcement ratio increases the ultimate punching resistance of the slabs about 18% , 21.5% , 25% for (s-2, s-3, s-4) respectively, with respect to s-1.

This is mainly due to the effect of reinforcement in resisting cracking propagation.

From comparison the ultimate experimental load with the ultimate load of ACI- 440 equation it's found that the ratios of their ranging from   (1.3 - 1.48).

Table (5): details of slabs with ultimate load

Slab	CFRP ratio %	Thickness of slab h (mm)	Column C(mm)	No. of bars in each direction	ρ_f/ρ_b. %	experimen load P_u(KN)	$P_{ACI-440}$ (KN)	$P_{exp.}/P_{aci}$
S – 1	0.3686	100	150	12	1.14	140	107.15	1.3
S – 2	0.3993	100	150	13	1.236	165	111.088	1.48
S – 3	0.43	100	150	14	1.33	170	114.93	1.48
S – 4	0.4607	100	150	15	1.426	175	118.65	1.48

5.3 Effect of Reinforcement Ratio on Load-Deflection Behavior and concrete strain of Slabs

Load-deflection curves for group 1 is shown in Figures (5-1) to (5-7). In general, all load deflection curves of all tested slabs have similar behavior and there are three stages can be seen in load-deflection curve. First, linear relationship between load and deflection this zone of load-deflection curve is called elastic zone and the first crack occurs at the end of this zone. Second, also linear relationship between load and deflection which is the load continue with deflection (loading stage), the third stage will start and the deflection continues to increase without any increasing in load (brittle failure). The deflection of all slabs is measured at two points, at center of slab and **2d** of the face of column. Its appear that with increasing reinforcement ratio the deflection is decreased during loading stage. Its noted that the average ratio of maximum deflection at (**2d**) of slab is (**0.7**) of the maximum deflection at center of slab.

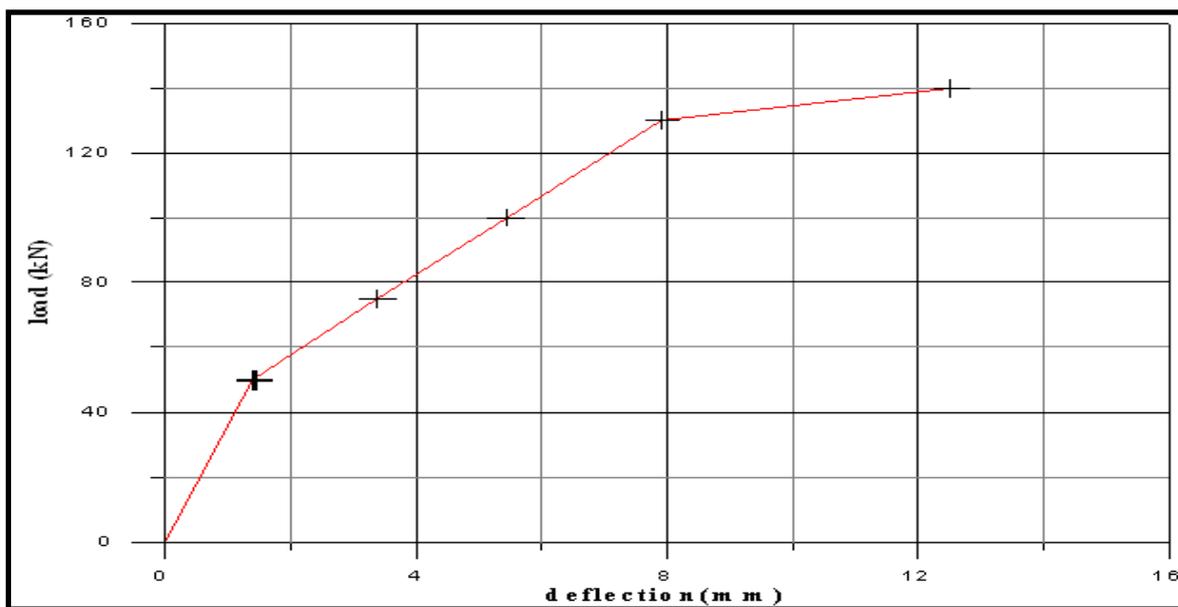Fig (5-1): Load – deflection curve of s – 1 & s – 11, at center of slab

Fig (5-2): Load – deflection curve of s – 1 & s – 11, at 2d of slab
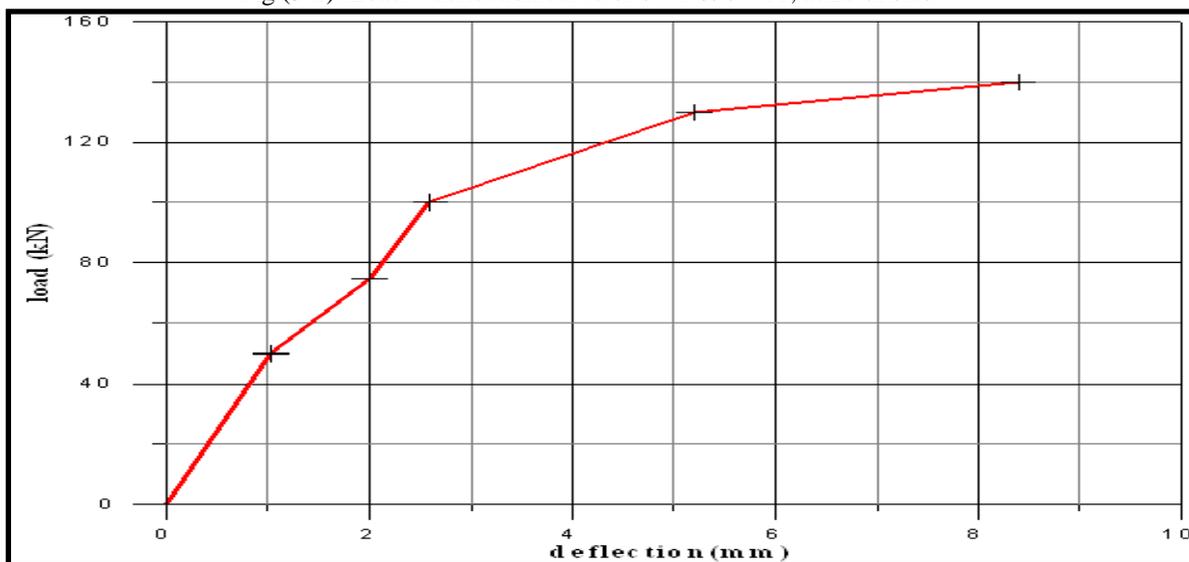

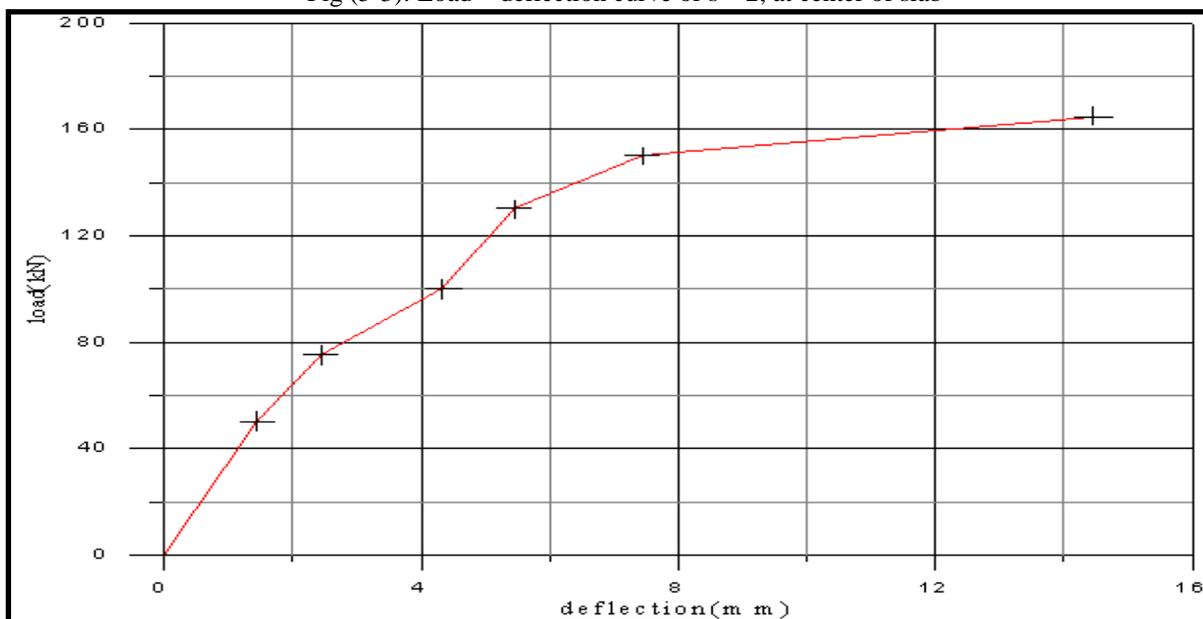Fig (5-3): Load – deflection curve of s – 2, at center of slab

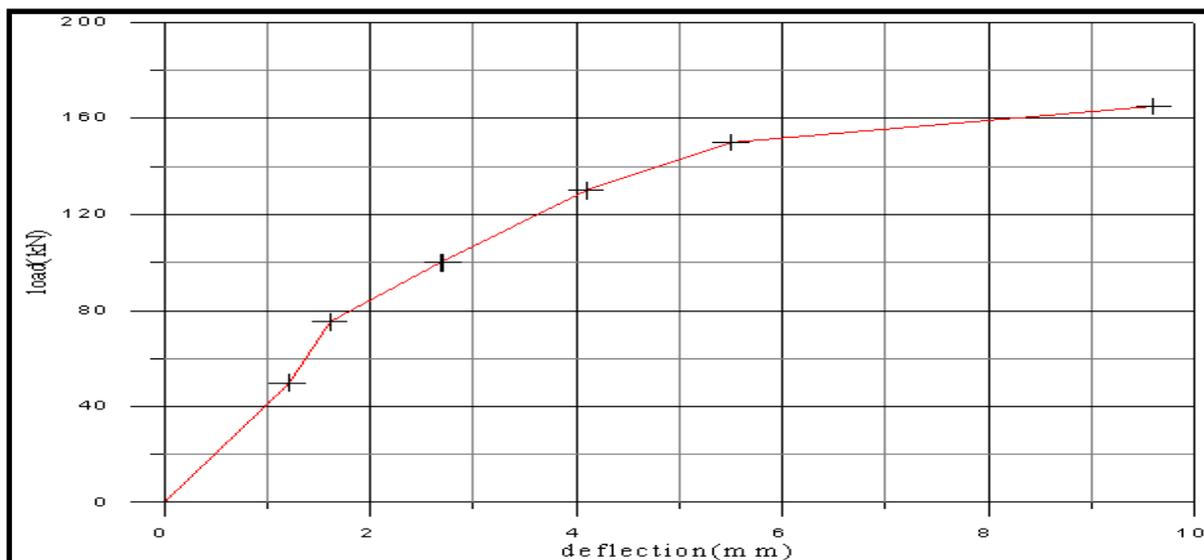Fig (5-4): Load – deflection curve of s – 2, at 2d of slab

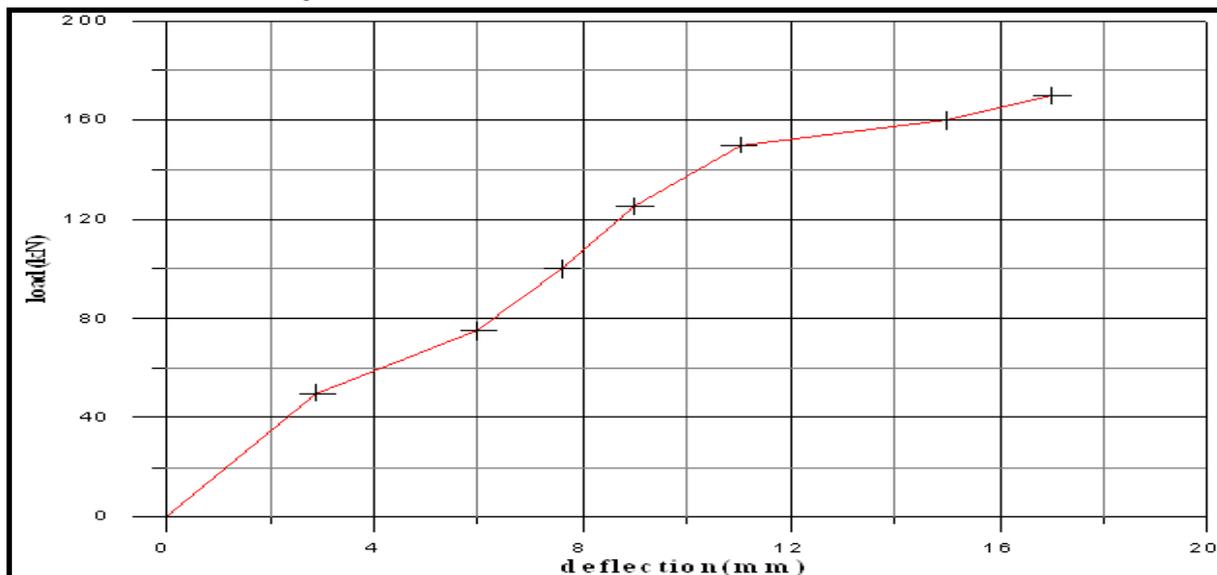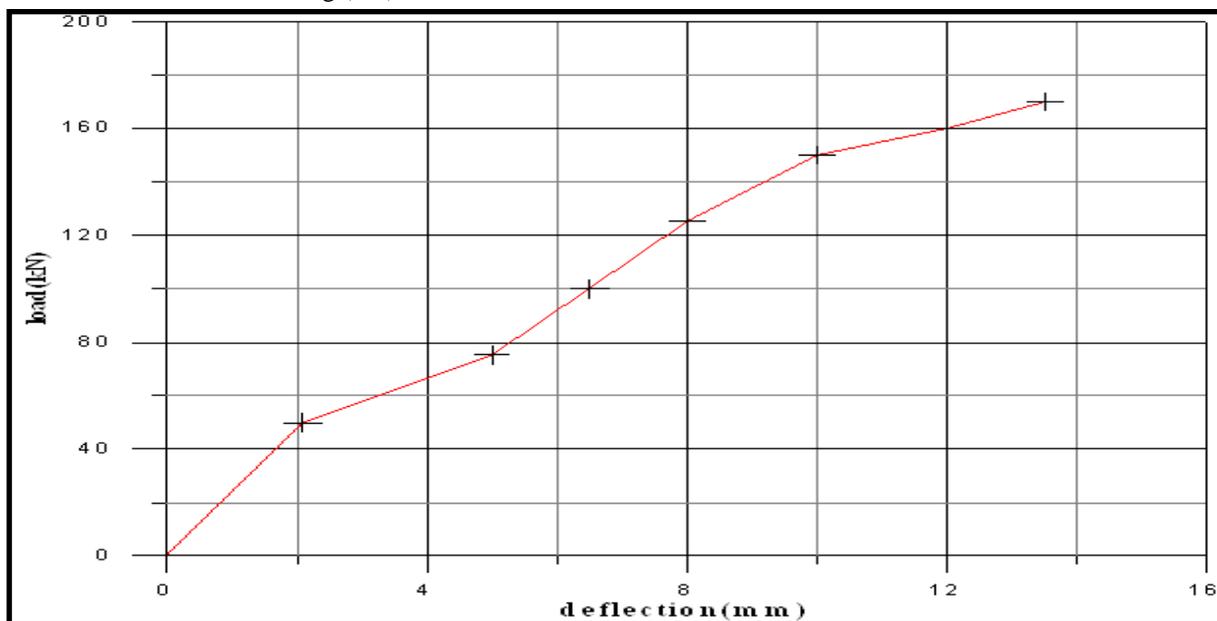Fig (5-5): Load – deflection curve of s – 3, at center of slab

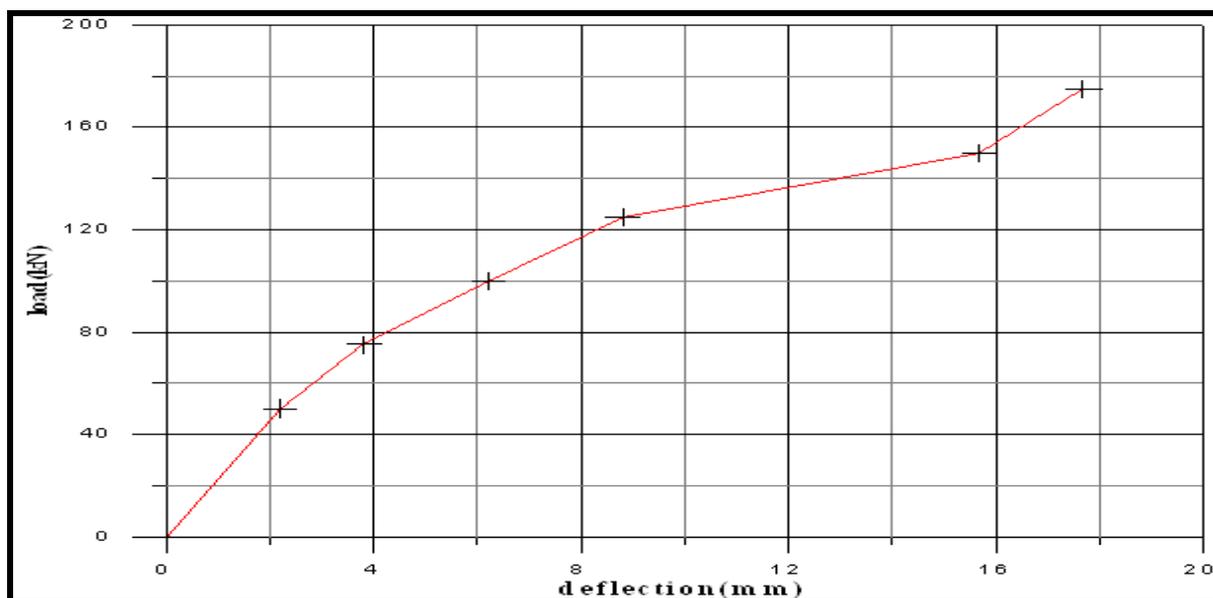Fig (5-6): Load – deflection curve of s – 3, at 2d of slab

Fig (5-7): Load – deflection curve of s – 4 & s - 6, at center of slab

6. Conclusions

1- No real workability problems are encountered for 2.0% volume fraction of hooked steel fibers used in the mix. However, RPC mixes require longer time for mixing (more than 15 min.) than NSC mixes, vibration, finishing and heat curing.

2- Mixing procedure and the performance of the mixer have a significant role on the resulting matrix as well as the physical properties of the RPC. However, the procedure which present for mixing used in the this work presents a successful way to produce RPC with a compressive strength equal 108 MPa.

3- Experimental tests of the fourteen RPC slabs reinforced by CFRP bars indicate that the first visible crack is observed at the tension face of the tested slab at load level equal to (32.21 – 35.28)% of ultimate load. Cracking on the tensile face began near the center and radiated towards the edges (semi- random phenomena).

4- By increasing the reinforcement ratio **8%**, the ultimate punching shear strength of RPC slab reinforced by CFRP bars increased by mean **17.8%**.

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