Punching Shear Strength Of Reactive Powder Concrete Slab Reinforced With CFRP Bars

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Abstract:

This work is devoted to study punching shear strength of reactive powder concrete slab reinforced with CFRP bars. The experimental program includes investigating the effect thickness of slab 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 سمك السقف على مقاومة القص الثاقب لسقوف المساحيق الفعاله المسلحه بواسطة قضبان الياف الكاربون البوليمريه

الخلاصة

يهتم البحث الحالي بدراسة تاثير سمك السقف على *مقاومة القص الثاقب لسقوف المساحيق الفعاله المسلحه بواسطة قضبان الياف الكاربون البوليمريه*. يتركز البرنامج العملي حول استقصاء تاثير سمك السقف 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

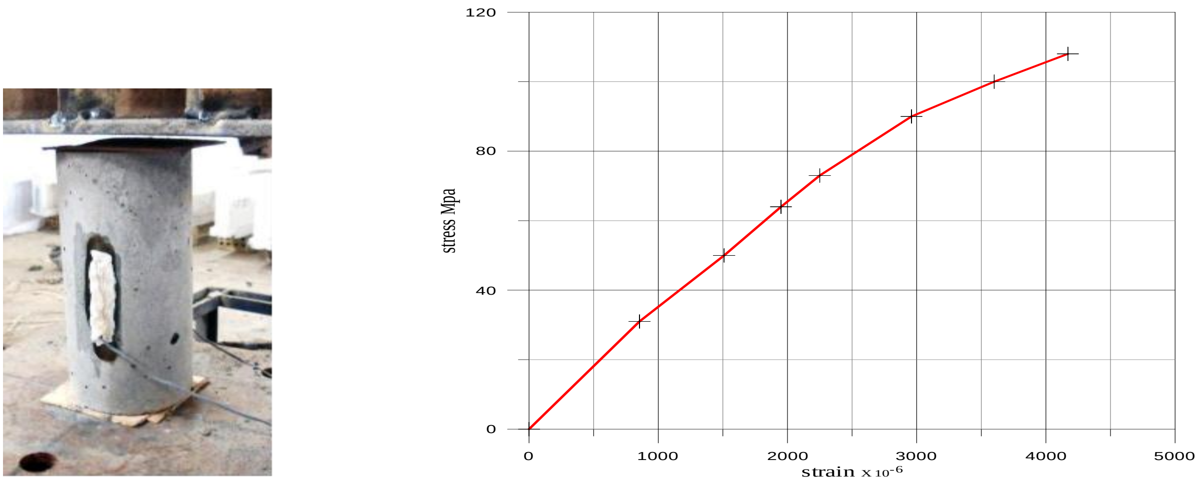
The trial mix 2 was considered which, it gave the maximum average compressive strength (108 Mpa) as show in table (3-2).

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***	***Arrangeme of reinforceme***
S – 1	0.368	80	150	12	One mes
S – 2	0.4607	100	150	15	One mes
S – 3	0.44217	120	150	18	One mes
S – 4	0.453	150	150	22	One mes

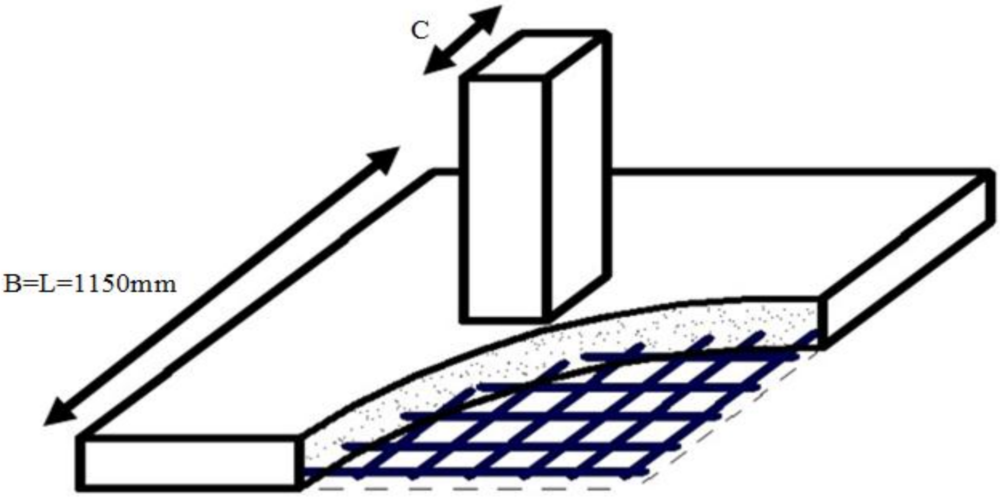


Fig (2): section of slab specimen

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 (3.334 – 55.56)% 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	80	0.368	90	30	33.334
S - 2	150	100	0.4607	175	60	34.28
S – 3	150	120	0.44217	155	55	35.48
S – 4	150	150	0.453	270	150	55.56

5.2 Effect of slab thickness

Table (5) shows the effect of the slab thickness on the ultimate punching resistance of the slab. Its noted that by increasing the thickness of slab the ultimate punching shear capacity is increased, and its noted that by increasing the thickness of slab approximately 55% that’s lead to increasing in punching resistance about 70%.

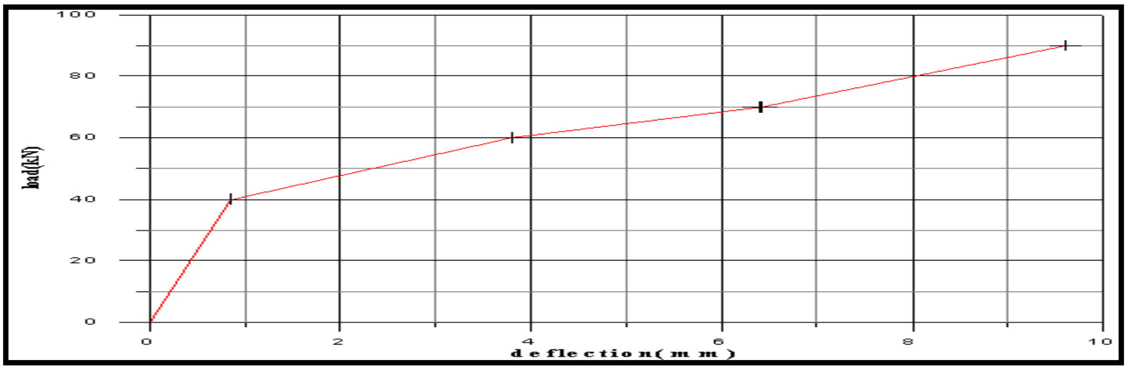
From comparison the ultimate experimental load with the ultimate load of ACI-440 equation it's found that the ratio of their ranging approximately from (1 - 1.475).

From figure (5-1) to figure (5-6), its noted that the deflection is decreased that’s because of the increasing in thickness of slabs and that’s causing increasing in moment of inertia of section (Ig). The average ratio of maximum deflection at (2d) of slab is (0.7) of the maximum deflection at center of slab.

Table (5): details of of slabs with ultimate load

Slab	**CFRP ratio %**	**Thickness of slab h (mm)**	**Column C(mm)**	**No. of bars in each direction**	**ρ_f / $\rho_{b.}$ %**	**experin tal load P_u(KN)**	**P_{ACI-4} (KN)**	**$P_{exp}./p_{a}$**
S – 5	0.368	80	150	12	1.14	90	73.36	1.23
S – 6	0.4607	100	150	15	1.426	175	118.65	1.475
S – 7	0.4421	120	150	18	1.37	155	155.22	1
S – 8	0.453	150	150	22	1.4	270	205.4	1.32

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



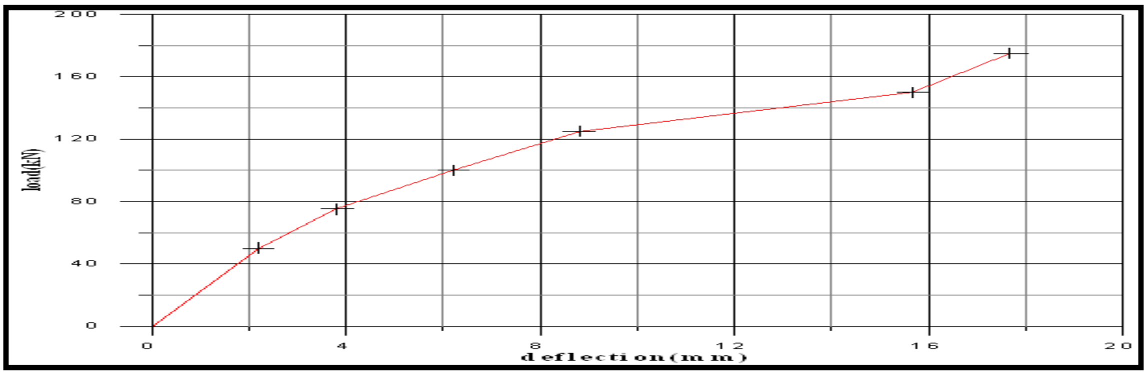


Fig (5-2):Load – deflection curve of s - 6, at center of slab

Fig (5-3):Load – deflection curve of s – 7, at center of slab

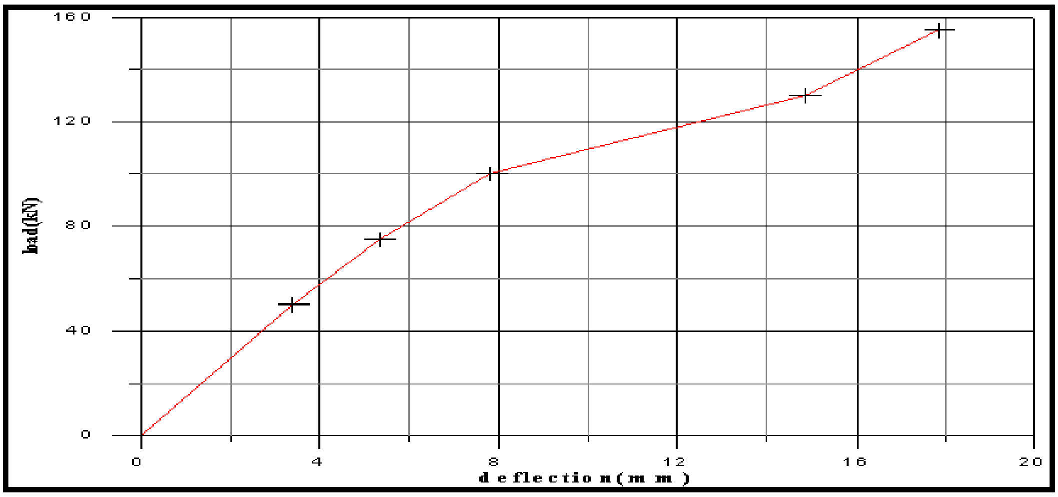


Fig (5-4):Load – deflection curve of s – 7, at 2d of slab

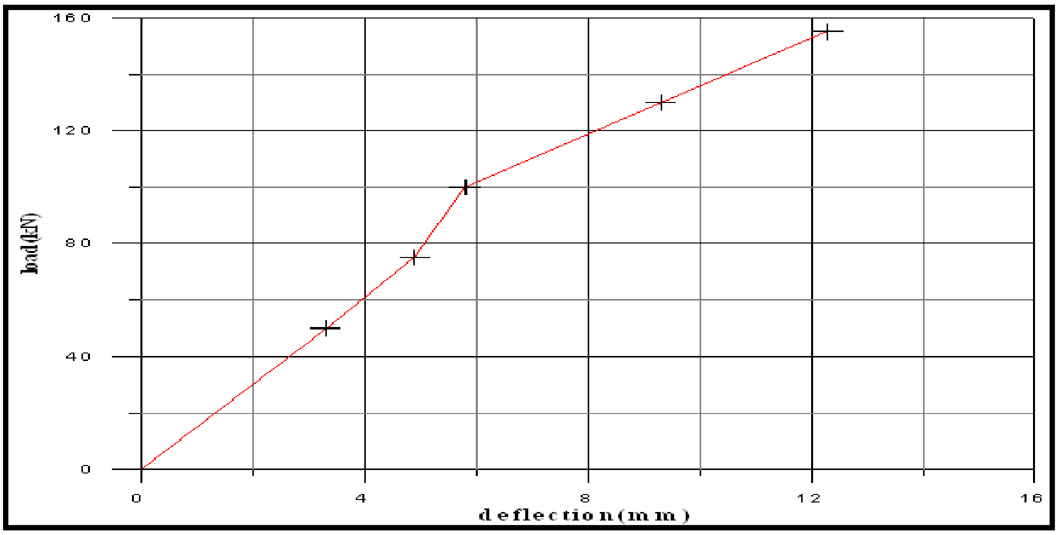
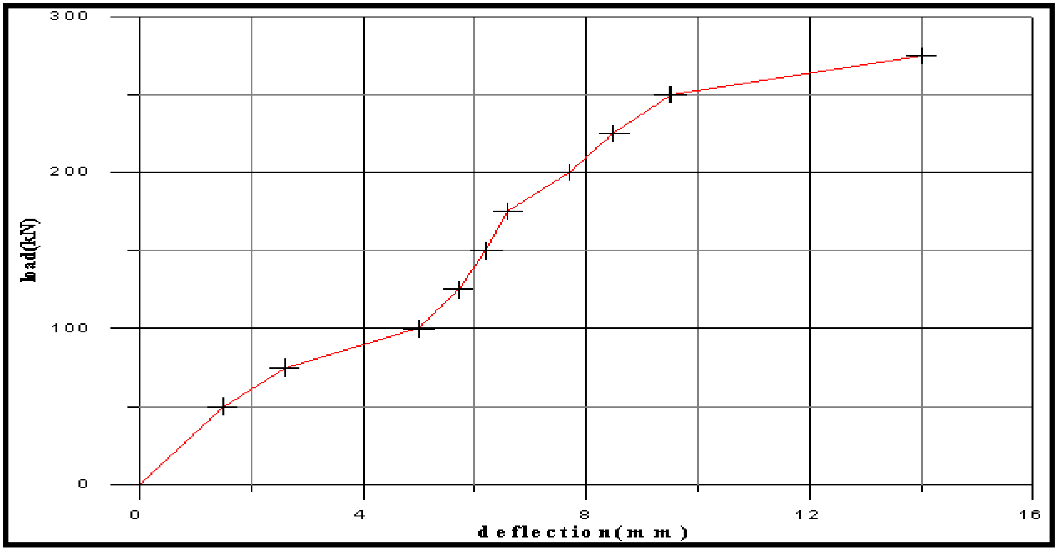


Fig (5-5):Load – deflection curve of s – 8, at center of slab



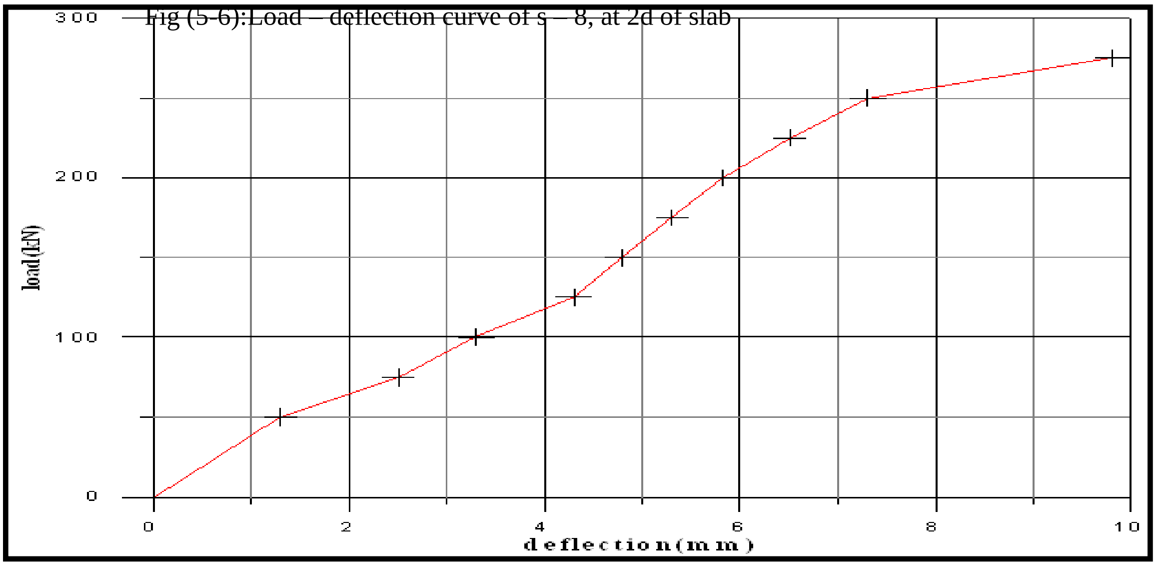


Fig (5-6):Load – deflection curve of s – 8, at 2d of slab

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 (33.334 – 55.56)% of ultimate load. Cracking on the tensile face began near the center and radiated towards the edges (semi- random phenomena).

4- The ultimate punching shear capacity is increased approximately 70% by increasing the thickness of RPC slab by 55%.

References

1. Ying, T., “*Behavior andModeling of Reinforced Concrete Slab-Column Connections*” , Ph.D. Thesis, The University of Texas at Austin, May, 2007.

2. Moe, J. “*Shearing Strength of Reinforced Concrete Slabs and Footings Under Concentrated Loads*”, Portland Cement Association, Research and Development Laboratories, Bulletin D47,April,1961.

3. Theresa, M.A., Erron J.P., Donald, L.M., *“Ultra High-Performance Concrete for Michigan Bridges Material Performance*”, Center for Structural Durability, Michigan Technological Transpiration Institute, Phase-I, Final Report – November, 2008.

4. Monai, B. and Schnabl, H., “*Practice of UHPC in Australia*”, Proceedings of Second International Symposium on Ultra High Performance Concrete, University of Kassel, Kassel, Germany, March 5-7, 2008, pp. 839-846.

5. Lee, N. P. and Chislom, D. M., “*Study Report on Reactive Powder Concrete*”, No. 146, Branz, Australia, 2006.

6. O'Neil, E.F., Neeley, B.D. and Cargile, J.D. “*Tensile Properties of Very High Strength Concrete for Penetration – Resistant [on line]*.” Us army engineers research and development center, 2001, pp.1-6.

7. Cheyrezy, M., Maret, V. and froun, L. “*Micro Structured Analysis of RPC (Reactive powder concrete)*” Cement and Concrete Research, Vol.25, Issue 7, 1995, pp. 1491-1500.

8. Dugat, J., Roux, N., “*Mechanical Properties of Reactive Powder Concrete*”, Materials and Structures,Vol.29, May1996, pp.233-240.

9. Aïtcin, P.C., “*Cements of Yesterday and Today Concrete of Tomorrow*”, Cement and Concrete Research, Vol.30, September 2000, pp. 1349-1359.

10. Richard, P., Cheyrezy, M., “*Composition of Reactive Powder Concrete*”, Cement and Concrete Research, Vol.25, No.7, 1995,pp.1501-1511.

11. Web site: www.ductal-lafarge.com/wps.

12 Yitizaki, D., "*Punching Strength of Reinforced Concrete Slabs*", ACI Journal, May 1966, PP. 527-540.

13 Neville, A. M., "*Properties of Concrete*", Longman Group, Ltd., Fourth and final edition, 2002; pp.83.