Evaluation of the Shear Strength of Reactive Powder Concrete Beam Reinforced with Fiber Reinforced Polymer Bars by Yield-Line Theory

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Abstract:

This paper investigates the shear strength capacity of Reactive Powder Concrete (RPC) beams reinforced with the different types of surface of the Carbon Fiber Reinforced Polymer (CFRP) bars as flexural reinforcement(smooth and Sand-coated CFRP). The shear equation of the JSCE code was adopted after modification. The modification is limited to the approximation of the steel fiber's contribution. The shear strength of the RPC with steel fibers and without shear reinforcement was derived by the researchers. The experimental works included twelve of the casted beams. Four of them were reinforced with steel reinforcement. Additionally, four beams were reinforced with smooth CFRP bars. The last group were reinforced , local manufacturing treatment of the surface, sand-coated CFRP bars. Two parameters are included in this study which are span-to-depth ratio (a/d) and the ratio of the longitudinal reinforcement (ρ_{w}) . The comparsion between the experimental results and those obtained by Yield line theory was performed. The shear strength of the yield line theory provided a shear strength of three times of shear strength for the steel-reinforcement and (4.5) times for sand-coated CFRP bars.

Keywords: Reactive Powder Concrete (RPC), FRP bars, shear Strength, Yield-line theory

INTRODUCTION :

In now days, an alternative to steel reinforcement for concrete structures is the composite materials that made of fibers embedded in a polymeric resin, known as FRPs. FRP materials have better properties than steel reinforcement such are nonmagnetic and noncorrosive due to polymer material, therefore the concerning problems can be avoided with FRP reinforcement. In the harsh environmental problem, two solution are available. The first one should be carried out by protection the concrete itself while the second solution is summarized by using stainless steel, epoxy-coated or providing cathodic protection of the reinforcement [1]. So, FRP material can be considered an excellent alternative these problems. There is three types of them which are Carbon (CFRP), Armid (AFRP) and Glass (GFRP). They have a wide range of applications either in new construction of the structure or strengthening purposes. The most common available types are shown in the figure Fig. 1

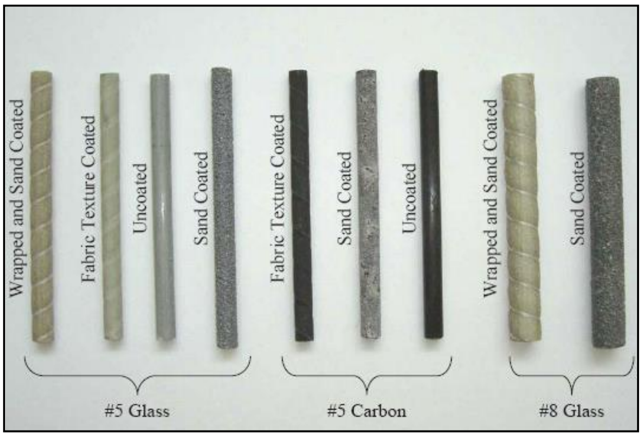


Fig. 1 Types of FRP Reinforcement

On the other hand, an improvements in concrete technology had been occurred. The development in superplasticizing admixtures lead to increasing of the properties and durable of concrete. This aim can be achieved by using silica fume material and high range water reducing "HRWR" liquid to produce a packing volume concrete. In the recent years ,the developed concrete named as Ultra High Strength Concrete (UHSC) is classified as Reactive Powder Concrete (RPC). [2], [3] ,[4], [5], [6] ,[7],[8]],[9] ,[10] &[11]

Richard and Cheyrezy(1995) [12] presented the following issues to develop RPC:

1. Utilized the fine sand , without gravel material, to improve the concrete's consistency.
2. Utilized the silica fume to increasing the pozzolanic reaction.
3. Getting the optimized granular mixture ,packing volume.

4. Increasing the compaction state by used pre-setting pressure.
5. Heat treatment to improvement the microstructure .
6. Existing of steel fibers to enhance the ductility.

LITERATURE REVIEW:

Alameer Ali [14], studied the shear strength of prestressed UHPC I – beam as well as the flexural behavior. He carried out the theoretical shear strength base on JSCE [15] and AFGC [16]. Also, he tried to use and additional truss analogy with constant crack inclination of (45°) along the same approach of JSCE (2006). In the French & Japanese approaches, the residual tensile strength of concrete assumed to be $(0.4 \times \sqrt{fc'})$ with the (B_u) inclination angle of strut based on lower bound of (30°).

Kai B. [16] used depended on a model shown in Fig. 2 ,which proposed by another researcher, without shear reinforcement was adopted in calculation the shear capacity of UHPC beams as follows

$$V_{u,ct} = \frac{2}{3} \cdot b_w \cdot k_x \cdot d. f_{ct} \cdot \left(\frac{4.d}{a}\right)^{\frac{1}{4}} \cdot \left(\frac{5.l_{ch}}{a}\right)^{\frac{1}{4}}$$

(1)

Where $l_{ch} = \frac{E_c\, G_f}{f_{ct}^{\,2}}$ is the characteristic length ; G_f is the fracture energy of HUPC and has a value of 143 N/m.

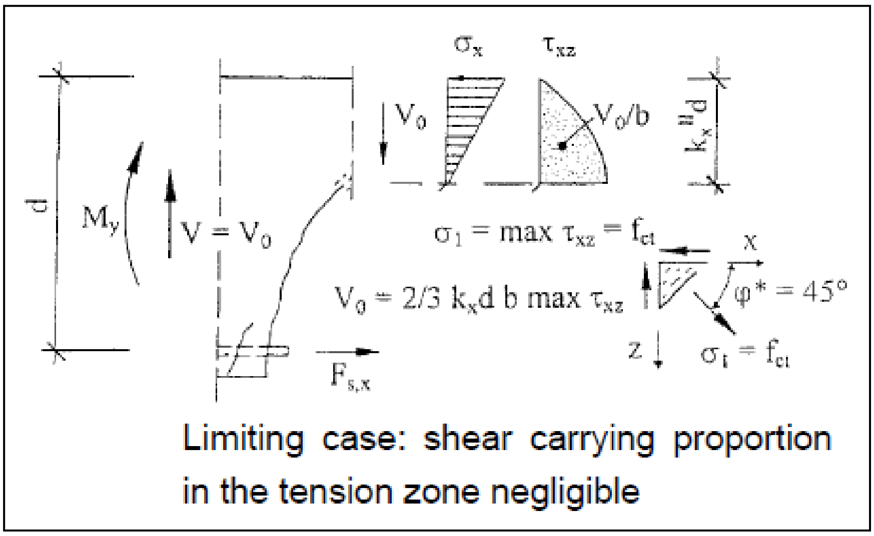


Fig. 2 Shear Mechanism

Colaianni [18] , developed a physical model for estimation the ultimate shear strength of concrete with steel fiber and without stirrups reinforcement called crack sliding model (CSM). This model based on yield line mechanisms. In this model, the diagonal crack had assumed as straight line from the bottom face to the loading's point with the horizontal projection (x).

The upper bound solution of plastic theory when $w_i = w_e$ will be:

$$\frac{1}{2}\times f_{C,eff}\times b\times(1-\sin\alpha)\frac{h}{\sin\beta}=P_u.u$$

(2)

$$\tau_u=\frac{P_u}{bh}=\frac{1}{2}\times f_{C,eff}\times\left[\sqrt{1+(\frac{a-x}{h})^2}-\frac{a-x}{h}\right]$$

(3)

where:

b = width of cross – section

$\alpha = 90 - \beta$; $\cot\alpha=\frac{a-x}{h}$; β = angle of diagonal

ρ_u = ultimate cracking load

u = ultimate vertical displacement

τ_u = average crack stress

The simultaneous tensile strain will develop in the cracked concrete, in compressive zone .The direction of this strain is normal to the compression. This phenomena called compression softening. In plastic theory ,it can be representation by the effectiveness factor of concrete. So, the effective compressive strength is :

$$(f_{C,eff}=V_C\times fc')$$

(4)

and

$$V_C=(0.35/\sqrt{fc})\ \left[0.27(1+1/\sqrt{h})\right]\ (0.15r+0.58)\times\left[1+0.17(a/h)-2.6\right]^2 \qquad (5)$$

r 100 A_s/bh

(6)

h = height of beam section
a = shear span

and by taking moment at point load:

$$\tau_{Cr} = \frac{P_{Cr}}{bh} = \frac{1}{2} \times f_{t,eff} \times \frac{\left[1 + (a - x/h)\right]^2}{a/h}$$

(7)

where:

$f_{t,eff}$ = effective tensile strength = $0.156 \times fc^{\frac{2}{3}} \times (h/0.01)^{-0.3}$

Finally, by equating (3) and (7) and solving using trial & error to find the horizontal projective of diagonal crack. The last term multiplying of equation of effectiveness factor is the arch action contribution when $(\frac{a}{d} \le 2.6)$. Finally he concluded that the compressive effectiveness factor increased from (0.5 to 0.97) for normal fiber concrete and (0.6) for high strength fiber concrete to take into account the ability of fiber to reduce the slips along to shear crack.

Voo [18] , used a crack-sliding model in calculation the shear strength (upper bound plasticity approach) of fiber reactive powder concrete prestressed beam. His study involved a seven full – scale girders failing in shear. He introduced a derivation of shear strength of rectangular cross – section as well as a Tee beam. For simply supported beam loaded with two symmetrically point load and for both pressed and non – prestressed with no shear reinforced, the ultimate load can be determined by:

$$V_u = \frac{1}{2} \times fc^* \times b \times h \left[\sqrt{1 + (\frac{x}{h})^2} - \frac{x}{h} \right]$$

(8)

where:
f_c^* = the effective concrete strength.
b & h = the width and depth of the section, respectively.
a = shear span.
x = horizontal projection of yield line.

By taken a moment around point (A) as illustrated in Fig. 3 and by defining a full uniform effective tensile stress bridging the crack, the ultimate load will equal cracking load and given by:

$$V_{Cr} = \frac{1}{2} \times ft^{*} \times b \times \frac{h^2 + x^2}{a} + \frac{\sum p_e . d_{p_i}}{a}$$

(9)

Where (d_{pi}) is the distance of effective prestressing force (p_e) from the top surface and (ft^*) is the effective tensile strength. The solution of both equations can be carried out by equating then and find the solution by trail & error procedure to find the horizontal procedure of yield line, giving:

$$fc*\left[\sqrt{1+(\frac{x}{h})^2} - \frac{x}{h})\right] = ft*(\frac{x^2+h^2}{ah}) + \frac{2\sum p_i .\ d_{p_i}}{abh}, \quad , \ 0 \le x \le a \qquad (10)$$

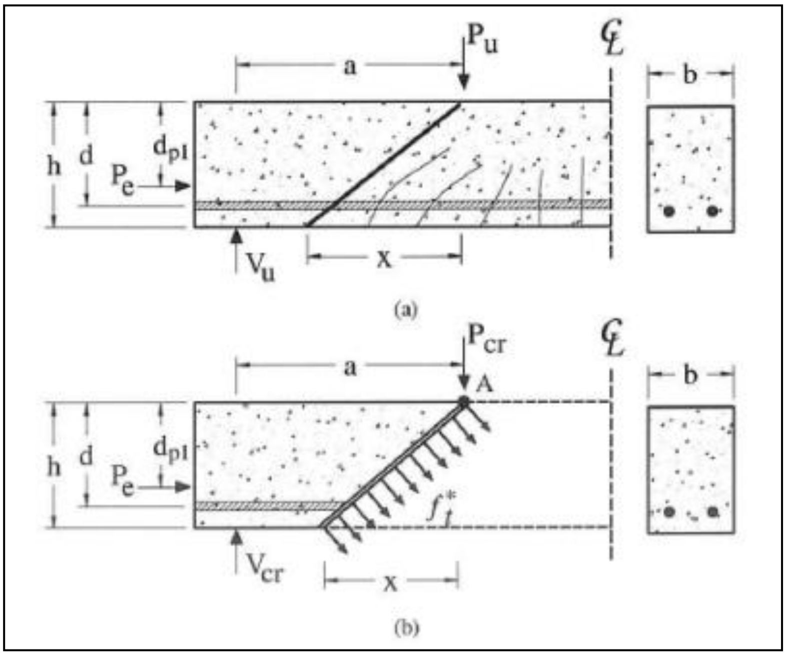


Fig. 3 Critical diagonal crack of S.S. beam (a) yield line and (b) cracking load

The effective compressive & tensile stress can be found by multiplying the compressive & tensile stress by corresponding factor (V_c & V_t), respectively. In his analysis, the effectiveness factors (V_c & V_t) were taken as (0.8).

EXPERIMENTAL WORKS:

Actually the experimental program is planned to cover more than this items of shear strength predicated by yield line theory. The casted beams have no shear reinforcement . The long of the shear beams was 1500 mm with 150 mm for width and depth, respectively. The length of the specimen was based on the minimum thickness to control the deflection as mentioned in ACI 440.1R-2006 [20], Fig.4 and Fig.5. The characteristic of all beams are shown in Table (1). All mechanical properties of RPC are obtained in the Civil Engineering's Laboratory-Collage of Engineering as shown in Table (2) , Table(3) and Fig.6 .

Fig. 4 Concrete Casting for specimens

Fig. 5 Testing for specimens

Table (1) : Main Features of the Tested Shear Beams

Feature of Beam	Theo. Flextural Failure load (kN)	Main Bottom Reinf. (A_r, mm^2)	Type of rebar	Effective depth	Shear span a(mm)	a/d ratio	Theo. Shear Failure load (kN)	Expected Failure Domain	Steel Stirrup for Shear span

S-1	192	4ø16 *mm* + 1ø10 *mm* (882.79)	Steel	82	287	3.5	138	Shear	Without stirrups
S-F-1 & S-S-1	150	10 ø6 *mm* (282.74)	CFRP	92	320		133	Shear	
S-2	234	4ø16 *mm* + 1ø10 *mm* (882.79)	Steel	82	246	3	138	Shear	Without stirrups
S-F- 2 & S-S-2	175	10 ø6 *mm* (282.79)	CFRP	92	276		133	Shear	
S-3	155	2ø16 *mm* + 2ø10 *mm* (559.2)	Steel	82	287	3.5	138	Shear	Without stirrups
S-F-3 & S-S-3	165	8ø6 *mm* (226.19)	CFRP	92	320		134	Shear	
S-4	181	2ø16 *mm* + 2ø10 *mm* (559.2)	Steel	82	246	3	138	Shear	Without stirrups
S-F-4 & S-S-4	165	8ø6 *mm* (226.19)	CFRP	92	276		134	Shear	

All shear beam were design to have enough flexural strength(over-reinforces cases) to ensure the shear failure. The calculation were done using EXCEL Program. The technique used to form the sand-coated FRP is summarized as follows:-

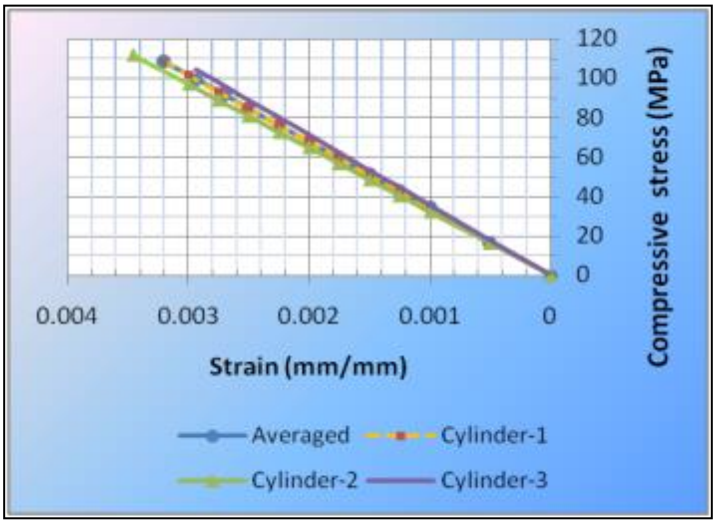
1- Applying sand blasting for the soomth CFRP bar.
2- Applying the espcial epoxy called (Sikadur ® 330) that bought from Sika Office in Baghdad-Al Mansour.
3- The fine sand was coated for curing period, 24 hours.

Table (2): Experimental Compressive Strength

Cube & Cylinder Test		Specimens' values			
f_{cu} 6.8 kN/sec	kN	1100.84		1030.51	1079.11
	MPa	110.1		103.1	107.91
	Average	107.04			
f'_c 2.4 kN/sec	kN	850.63	877.42	820.82	859.23
	MPa	108.31	111.74	104.51	109.4
	Average	108.5			
$\frac{f'_c}{f_{cu}}$		0.986			

Table (3): Experimental values for the tensile strength

Cylinder & Prisms Test		Specimens' values		
f'_{sp} 0.94 kN/sec	kN	237.1	222.45	225.23
	MPa	7.55	7.08	7.169
	Average	7.27		
f'_r 0.2 kN/sec	kN	30.165	29.337	32.624
	MPa	20.361	19.824	22.021
	Average	20.74		
$\frac{f'_{sp}}{f'_r}$		0.35		



a) 2 strain gauges for tested b)

Experimental Stress-Strain curve

cylinder

Fig. 6 Compressive stress-strain curve

DISCUSSION :

In order to investigate the upper bound of the shear strength of the RPC without stirrups, the Yield Line Approach that adopted by Voo [19] and Colaianni [18] was introduced. The main solution depended on the trial and error procedure to evaluate the crack projection (x) and then calculation of the ultimate shear failure, Table (4).

Table (4): Ultimate shear force –Yield Line Approach

Beam Symbol	Reinf. Ratio	Reinforcement Type	Theoretical Data, Yield line approach		Experimental Ultimate Shear Load (kN)	$\frac{V_{u,Theo.}}{V_{u,Exp.}}$
			Crack Projection (mm)	Ultimate Shear Load (kN)		
S-1	0.07	Steel	115	406	123	3.3
S-2	0.07	Steel	117	410	133	3.1
S-3	0.045	Steel	115	406	118	3.44
S-4	0.045	Steel	117	410	129	3.2
S-F-1	0.02	Smooth-CFRP	115	406	70	5.8
S-F-2	0.02	Smooth-CFRP	117	410	77	5.3
S-F-3	0.016	Smooth-CFRP	115	406	56	7.25
S-F-4	0.016	Smooth-CFRP	117	410	65	6.3
S-S-1	0.02	Sand-Coated CFRP	115	406	89.7	4.5
S-S-2	0.02	Sand-Coated CFRP	117	410	92.6	4.4
S-S-3	0.016	Sand-Coated CFRP	115	406	84.6	4.8
S-S-4	0.016	Sand-Coated CFRP	117	410	90.1	4.55

The averaged ratio of the upper-bound shear failure load to the corresponding experimental shear failure load is about three times for steel reinforcement and about six times for smooth CFRP bars. The bonding strength of the smooth bar gave the lowest values. This approach provide a safety factor of (3) that can be applicable to determine the shear of the RPC beam. The comparsion for sand-coated CFRP beams display that the safety factor of (4.5). The increasing in safety factor reflects the fact that the absence of dowel-action components for CFRP bar itself.

CONCLUSIONS:

1. The shear strength that predicated by Yield-line theory shows the upper-bound limit.
2. The ultimate shear capacity for RPC without shear reinforcement that predicated by Yield Line Theory provided safety factor of (3) when the section reinforced by steel reinforcement and (4.5) for sand-coated CFRP beams.

REFERENCES :

[1] Meleka N.N. , A.A.Bashandy and M.A.Arab (2014) ,"Behavior and Analysis of Economically Reactive Powder RC Beams ", Asian journal of civil engineering (BHRC), Vol.15,No.5.

[2] Anjan k.M., Asha U. Rao, Narayana Sabhahit "Reactive Powder Concrete Properties with Cement Replacement Using Waste Material",Indian International Journal of Scientific & Engineering Research Volume 4, Issue 5, May-2013 .

[3] Behzad Nematollahi, Raizal Saifulnaz M. R., Mohd. Saleh Jaafar & Yen Lei Voo" A review on ultra high performance 'ductile' concrete (UHPdC) Technology",2010, International Journal oF Civil and Structural Engineering, Volume 2, No. 3, Malaysia .

[4] Fujikake F. , Takanori S. , Nobuhito U. , Tomonori O. and Makoto Katagiri (2005)," Nonlinear Analysis for Reactive Powder Concrete Beams Under Rapid Flexural Loading ", Journal of Advanced Concrete Technology, Vol.4 , No.1 , PP. 85-97 , Japan Concrete Institute.

[5] Graybeal B. and Marshall D. (2008), " Cylinder or Cubes: Strength testing of 80 to 200 MPa (11.6 to 29 ksi) Ultra-High-Performance Fiber-Reinforced Concrete" , ACI Materials Journal, Technical Paper, No. 105-M68 .

[6] Mahesh Maroliya (2012) , " Bond Strength Of Reactive Powder Concrete Containing Steel Fiber and Silica Fume", International Journal of Emerging Technology and Advanced Engineering, Volume 2, Issue 10 , Website: www.ijetae.com (ISSN 2250-2459).

[7] Pierre Richard and Marcel Cheyrezy, "Composition of reactive powder concretes," Cement and Concrete Research, Vol. 25. No. 7, pp. 1501-1511,1995.

[8] Prabhat R. Prem , B.H.Bharatkumar and Nagesh R Lyer(2012) , "Mechanical Properties Of Ultra High Performance Concrete ", World Academy of Science ,Engineering and Technology ,Vol.68 2012 -08-23 .

[9] Rachael A. Price (2009),"Mechanics of Fiber Reinforced Reactive Powder Concrete (RPC)", Initial Thesis Report, UNSW@ADFA .

[10] Tao Ji , Caiyi Chen , Baochun Chen and Yizhou Zhuang, (2011), "Study on Cracking Resistant Behavior of Reactive Powder Concrete ", 3rd Chinese-Croatian Joint Colloquium, Sustainable Arch Bridges, Zagred-Croatia .

[12] Țibea Ciprian, Bompa Dan, Văgîi Victor, Măgureanu Cornelia " ULTRA HIGH PERFORMANCE FIBER REINFORCED CONCRETE "I" BEAMS SUBJECTED TO SHEAR ACTION" ,2012,Journal of Civil Engineering & Architecture Vol. 55 No. 2,Romania .

[13] Raffaello, Fico (2008),"Limit States Design of Concrete Structures Reinforcedwith FRP Bars", Ph.D. thesis, University of Naples Federico II.

[14] Alameer Ali (2013),"Behavior of Prestressed Ultra-High Performance Concrete I-Beams Subjected to Shear And Flexure ", Master Thesis, Applied Science in Civil Engineering ,Ottawa University, Canada.

[15] Yuichi Uchida, Junichiro Niwa , Yoshihiro Tanaka and Makoto Katagiri (2004)," Outlines of "Recommendations For Design And Construction of

Ultra High Strength Fiber Reinforced Concrete Structures" By JSCE ", Concrete Committee of Japan Society of Civil Engineers.

[16] Jacques Resplendino (2002), " First Recommendation for Ultra-High-Performance Concrete and examples of application", French recommendation, AFGC-SETRA work group.

[17] Kai Bunje and Ekkehard Fehling (2004), " About shear force and punching shear resistance of structural elements of Ultra High Performance Concrete ", Ultra High Performance Concrete (UHPC), International Symposium on Ultra High Performance Concrete ,PP: 401- 411, Kassel University, Germany.

[18] Colaianni P. ,A.Recupero &N.Spinella (2008),"A model For SFRC Beams without Shear Reinforcement ", Tailor Made Concrete Structure – Walraven & Stoellhost (eds) , Talyor &Francis Group , London , ISBN 978-0-415-47535-8 .

[19] Voo J Y L,S J Foster and G I Gilbert (2003)," shear Strength of Fiber Reinforced Reactive Powder Concrete Girders without Stirrups", Studies from School of Civil and Environmental Engineering, New South Wales University, UNICIV Report No. R-421 November 2004, Sydney, Australia.

[20] ACI 440.1R-06 (2006), "Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars", American Concrete Institute.