Flexural Behavior Of Reactive Powder Concrete Beam Reinforced With Sand - Coated Cfrp Bars By Finite Element Analysis

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Obstruct

This paper investigates the modeling of the Reactive Powder Concrete (RPC) beams reinforced with the different types of the reinforcement (steel and Sand-coated CFRP). The ANSYS 11 program was used. The experimental works included casting of eight RPC concrete beams. Four of them reinforced with steel bars, while the others were casted using sand-coated CFRP bars. The mechanical properties of the RPC were experimentally obtained. The manufacturing data were used for CFRP bars. The RPC was modeled by Solid 65 element. The steel plate for loading and support was modeled by. The steel and CFRP Bars were modeled by discrete bar element. The study includes the effect of the distribution of the steel fibers on the flexural behavior in term of load-deflection relation. The uniformly distributed of the steel fiber longitudinally and vertically gave the best behavior than the corresponding experimental results for both types of reinforcements.

Keywords: Reactive Powder Concrete (RPC); FRP bars; Flexural Strength; Finite Element

سلوك الانحناء لعتبات خرسانة المساحيق الفعالة المسلحة بقضبان ألياف البوليمرات الكاربونية المسحلة والمطلية بالرمل باستخدام تحليل العناصر المحددة

المستخلص

يتحرى هذا البحث تمثيل عتبات خرسانة المساحيق الفعّالة المسلحة بقضبان الحديد و قضبان ألياف البوليمرات الكاربونية المسلحة ذات سطح مطلي بالرمل. تم استخدام برنامج المسمى (ANSYS 11). العمل المختبري تضمن صب ثمانية نماذج خرسانية. اربعة منها مسلحة بقضبان حديد التسليح ، اما البقية فمسلحة بقضبان البوليمرات المطلية بالرمل. الخصائص الميكانيكية لخرسانة المساحيق الفعالة تم الحصول عليها مختبريا. خرسانة المساحيق الفعالة تم تمثيلها بعنصر خرساني (Concrete 65) . الصفيحة المعدنية للحمل والمسند تم تمثيلها بعنصر (Solid 85) . قضبان حديد التسليح والبوليمرات تم تمثيلها بعنصر عتبي (Bar element). الدراسة تضمنت تأثير توزيع الياف الحديد على تصرف الانحناء بدلالة علاقة الحمل- الهطول. تم الاستنتاج بان توزيع الياف الحديد بشكل متساوي وبالاتجاهين افقي وعمودي اعطى نتائج قريبة لنظيرتها العملية لكلي نوعي التسليح.

1. 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 (1).

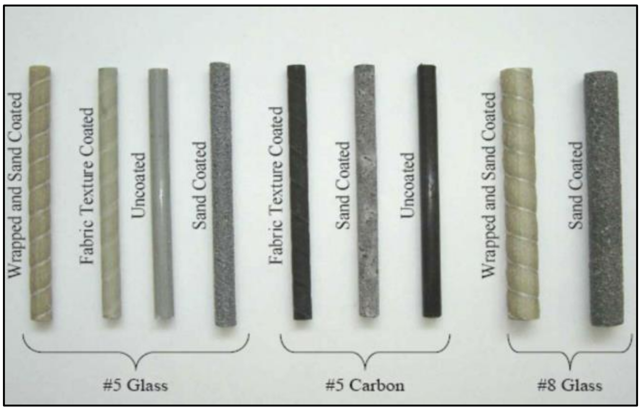


Figure (1). Types of FRP Reinforcement

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 [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.

Now days, a numerical solution of FEM are widely utilized in solving of the structural problems. The large systems of algebraic equations were firstly assembled and then solved using computer abilities[13].

Many of commercial finite element programs like ANSYS, NASTRAN, SAP, and etc. were used. The selection of the ANSYS software was due to many advantage such as modeling the concrete material , steel reinforcement element, stress-strain curve for concrete and reinforced bars, concrete crack/crush, failure criterion because absence of yield point of CFRP bar, modeling of steel fibers, simple way of output date and capturing the pictures at any time.

2. Literature Review

Kaiss [14] used a three-dimensional 20-node brick element to represent the reactive powder concrete beam failing in shear. The reinforced bar was modelled by the axial member built into concrete elements and was assumed to transmit the axial force only. An empirical equations to represent the uniaxial compressive strength and peak tensile stress were used as

$$f_c^{'}= 3.35*(f_c^{'})^{0.8}(f)^{0.05} \quad (1)$$

$$ft=3.37*(f_c^{'})^{0.8}(f)^{0.2} \quad (2)$$

Mahesh [15] investigated the possibility of representation of RPC material by ANSYA software as well as the restrictions. A sequare plate with one opening and 60cm thickness. A 4-noded brick element to represent the RPC materials. Due to symmetry of loading, geometry and condition, one part of "L" shape was selected to model the overall plate.

Maleka [16] used a nonlinear computer program to study the behavior of RPC beam by using the quadrilateral parametric degenerated layer thick shell elements. Each node have three degree of freedom and each element has eight node. He found that the tensile strength used in FEA is 80% of the 28th day of RPC beam casting by indirect tension test result.

Ouday [17] studied the high strength concrete of 60 MPa reinforced with CFRP bars. The concrete was modeled by ANSYS of solid 65 element. The CFRP bar was modeled by discrete bar element with spring to evaluate the bar’s slip.

3. Experimental Works

The flexural beams included two groups. The first group consists of four beams reinforced with steel bars. One of them was designed to fail by bar rupture failure while the others were designed to fail by concrete crushing (over-reinforced), as per principles of ACI 440.1R-2006 [18]. The same beams were designed with same principle but with sand-coated CFRP bars. All beams have the same flexural strength. The long of the flexural beams was 3400 mm with 250 mm and 150 mm for depth and width, respectively. The length of the specimen was based on the minimum thickness to control the deflection as mentioned in ACI 440.1R-2006 [18], Figure (4) and Figure (5) . The characteristics of all beams are shown in Table (1). All mechanical properties of RPC are obtained in the Civil Engineering's Laboratory-Collage of Engineering of Missan University as shown in
Table (2) , Table (3) and Figure (6).

Figure (4). Concrete Casting for specimens

Figure (5).Testing for specimens

All beam were design to have enough flexural strength (under and over-reinforces cases) to ensure failure's mode. 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 smooth CFRP bar.
2- Applying the especial epoxy called (Sikadur ® 330) that brought from Sika Office in Baghdad-Al Mansour.
3- The fine sand was coated for curing period, 24 hours.

Table (1). Main Features of the Tested Flexural Beams

Beam Sym.	Reinforce-ment state	Load (kN)	Flexural Strength (kN.m)	Flexural Strength Ratio (Steel/ CFRP)	Main Bottom Reinf. (A, mm^2)	Type of rebar	Effective depth $d\ (mm)$	Steel Stirrup for Shear span
F-1	Under-Reifocred	116.72	43.19	0.985	2Ø12 *mm* + 1Ø10 *mm* + 3 Ø 6 *mm* (389.56)	Steel	185.5	Ø6 @ 100 mm
F-S-1		118.42	43.81		2Ø6 *mm* (56.55)	S-C CFRP*	201	
F-2	Over-Reifocred Case 1	146.13	54.07	1.005	2Ø12 *mm* + 2Ø10 *mm* + 1Ø6 *mm* (411.55)	Steel	185.5	Ø6 @ 100 mm
F-S-2		145.34	53.78		3Ø6 *mm* (84.823)	S-C CFRP	201	
F-3	Over-Reifocred Case 2	158.85	58.77	0.982	2Ø16 *mm* + 3Ø 6 *mm* (486.95)	Steel	183.5	Ø6 @ 100 mm
F-S-3		161.74	59.84		4Ø6 *mm* (113.09)	S-C CFRP	201	
F- 4	Over-Reifocred Case 3	177.6	65.71	1.01	2Ø16 *mm* + 1Ø10 *mm* + 4Ø6 *mm* (593.76)	Steel	183.5	Ø6 @ 100 mm
F-S-4		175.67	65		5Ø6 *mm* (141.37)	S-C CFRP	201	

* S-C

CFRP denoted to Sand-coated CFRP Reinforcement.

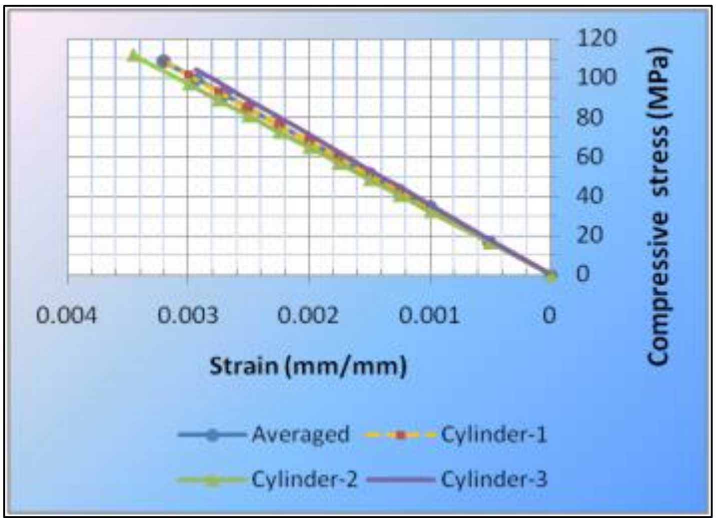
Table (2). Experimental Compressive Strength

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			
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		
f_{sp}'/f_r'		0.35		

a) 2 strain gauges for tested cylinder



b) Experimental Stress-Strain curve

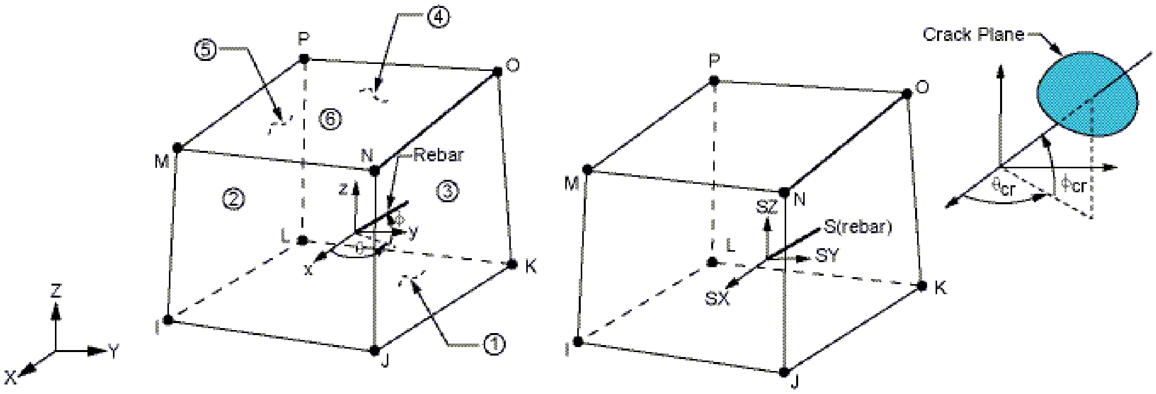
Figure (6). Compressive stress-strain curve

4. Finite Element Models by ANSYS

To model the concrete, the Solid65 element was used which have eight nodes. Each node has three degrees of freedom in x, y, and z directions as translational. It also has cracking option in three orthogonal directions , crushing and three embedded bars with any entity angle. The element types for this model are shown in Table (4).

Table (4). Types of Element in the Present Study

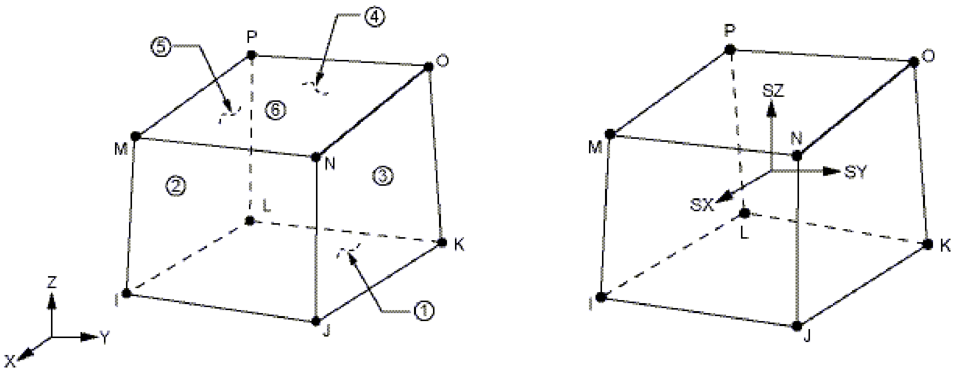
Material Type	ANSYS Element
Concrete	SOLID 65
Steel Plates and Supports	SOLID 185
Steel Reinforcement	LINK 180
CFRP Reinforcement	LINK 180



a) Element's Geometry **b) Stress Output**

Figure (7). Configuration of SOLID 65 Element

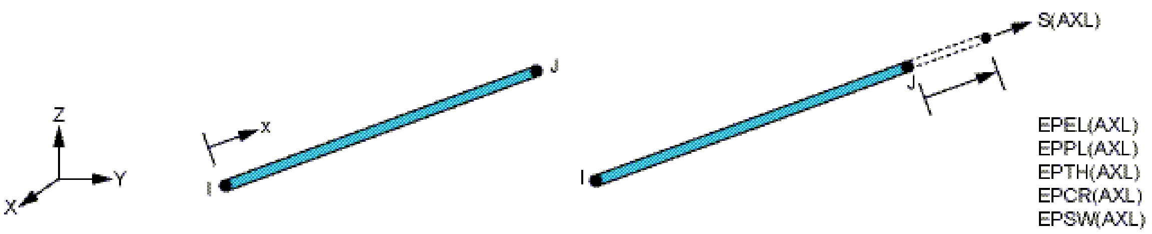
The steel plates of supports and steel plate of the applied load were modeled by a Solid185 element. This element has eight nodes. Each node has three translational degrees of freedom x, y, and z directions. The geometry of this element are shown in Figure (8).



a) Element's Geometry **b) Stress Output**

Figure (8). Configuration of SOLID185

All reinforcement rebars (Sand-coated CFRP, main longitudinal flexural rebars and stirrups) were modeled by the Link180 element .It is a 3Dspar element with two nodes and each node has three degrees of freedom in orthogonal directions as shown in Figure (9).



a) Element's Geometry b) Link180 Stress Output

Figure (9). LINK180 (CFRP and Steel Rebar)

4.1 Real Constants

Another entity for proper modeling is the real constants. It is worth to mentioned that many real constants may be inputted for an individual element. ANSYS neglected any entity of real constant for this element. All used real constants are tabulated below in Table (5).

Table (5). Real constants for ANSYS Models

Real constant set	Element type	Constants			
1	LINK180	Cross-sectional area (mm^2)- Ø 6 mm		28.27	
2	LINK180	Cross-sectional area (mm^2) - Ø 10 mm		78.54	
3	LINK180	Cross-sectional area (mm^2) - Ø 12 mm		113.1	
4	LINK180	Cross-sectional area (mm^2) - Ø 16 mm		201	
5	LINK180	Cross-sectional area (mm^2) - Ø 25 mm		409.87	
6	LINK180	Cross-sectional area (mm^2) - Ø 6 mm-CFRP		28.27	
7	SOLID65	Properties	Real constants		
			rebar1	rebar2	rebar3
		Material number	Under study	Under study	Under study
		Volume ratio	Under study	Under study	Under study
		Orientation angle THETA(horizontal angle)	Under study	Under study	Under study
		Orientation angle PHI (Vertical angle)	Under study	Under study	Under study

4.2 Steel Fiber Model

Generally, it is easy to model all components of the beam, flexural and shear, even the CFRP bars. The one thing that have a doubt about its modeling is the steel fiber. The main issue in this modeling is its actual distribution in space of the specimen. In order to overcome on this issue, the variety of the models for steel fiber are included in this study and the comparsion with experimental results either the model convergence or divergence. As mentioned before , the Concrete Element of Solid 65 provides three smeared bar with different angle of rotation. In this study the model was created for plain element of Solid 65,lumped steel fiber as individual horizontally, vertically, inclined manner with 45^{o} of one-way distribution. The two-way distribution was included as horizontal and vertical as equally distribution. Finally, the three -way equal distribution in horizontal, vertical and inclined of 45^{o} distribution is proposed. The input data and modeling are shown in the Figure (10) to Figure (13).The comparsion study among these models will illustrated hereafter

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Figure (9). Input data of steel fiber modeling, One- way , Horizontal distribution

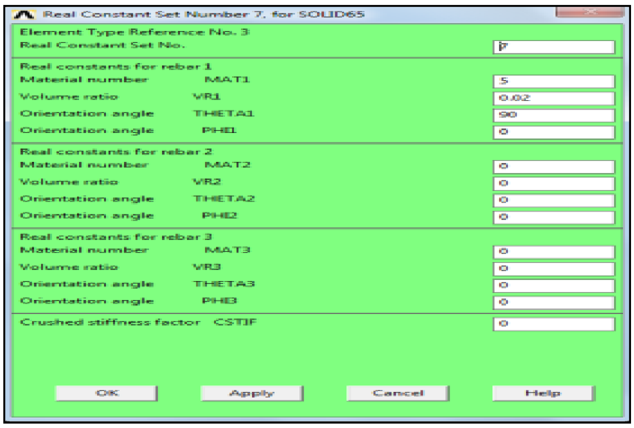


Figure (10). Input data of steel fiber modeling , One-way ,Vertical distribution

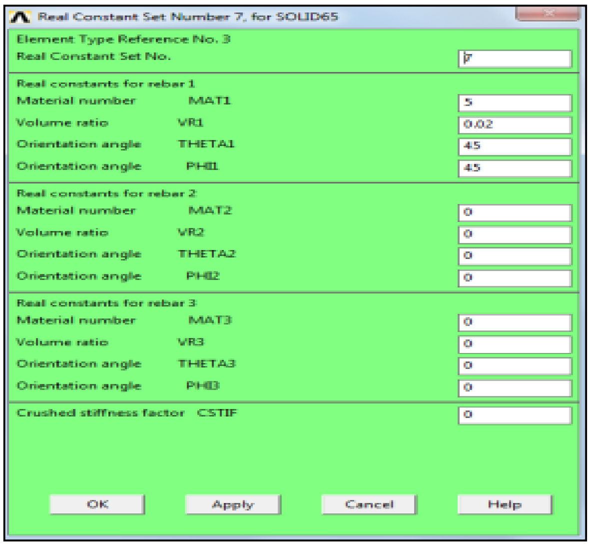


Figure (11). Input data of steel fiber one- way , Inclined distribution

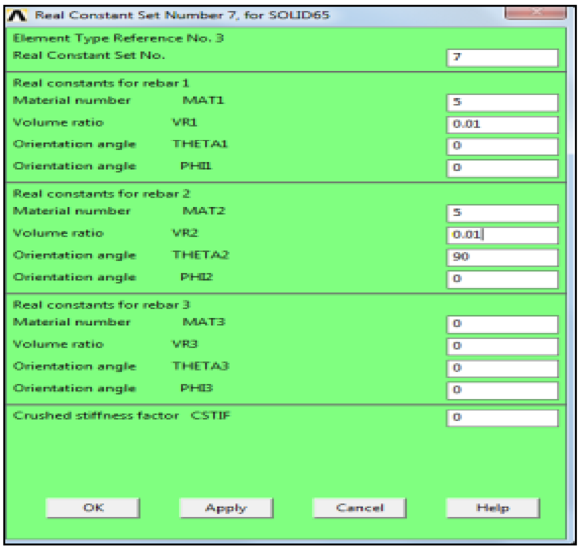


Figure (12). Input data of steel fiber,two-way distribution

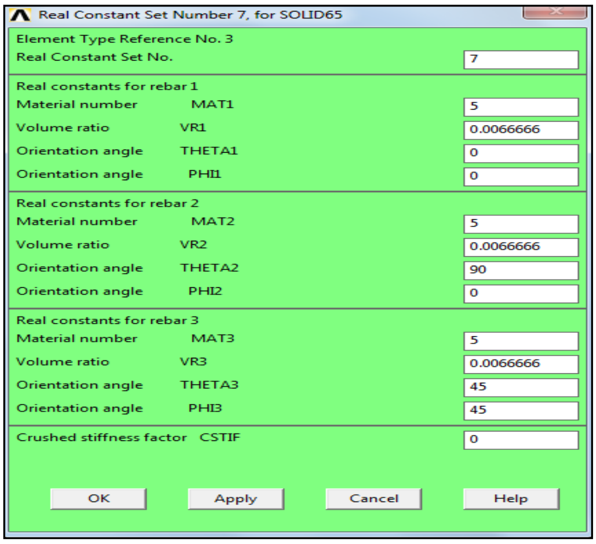


Figure (13). Input data of steel fiber modeling, Three- way distribution

4.3 Loads and Boundary Conditions

In order to get a unique solution, the constrain should be carried out. The applied of boundary conditions was done in ANSYS 11 as applied specific displacement with zero value. To keep the model behaves like the experimental beam, the boundary conditions need to be applied along the axis of symmetry. The boundary conditions state of the beam is shown in Figure (14). All nodes of the vertical plane of symmetry must be constrained in the perpendicular directions (UZ = 0 and UX = 0) and allow the vertical movement. The roller support was modeled by constrained, in the Y direction, the nodes that lie in mid-line of plate. The rotational movement was allowed to complete the modeling of the roller. The support condition is shown in Figure

(14). The applied forces was modeled as a lumped at the steel plate. The force applied at each internal node of the actual force and have a magnitude a twice that applied at each of the two external nodes on the plate.

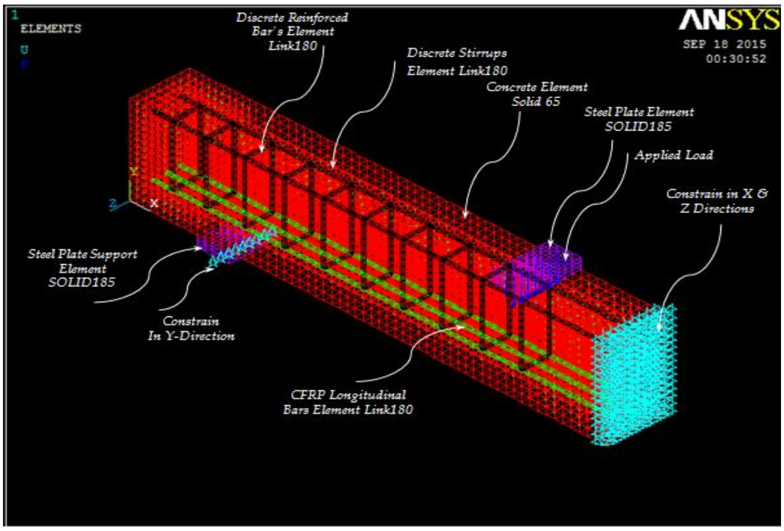


Figure (14). Typical details of FE mesh used for the analysis of concrete beam

4.4 Analysis Type

Actually, the static analysis was used for analyzed the models of all beams utilized in this study. The Sol'n Controls commands used in this analysis was illustrated in Figure (15) to Figure (18).

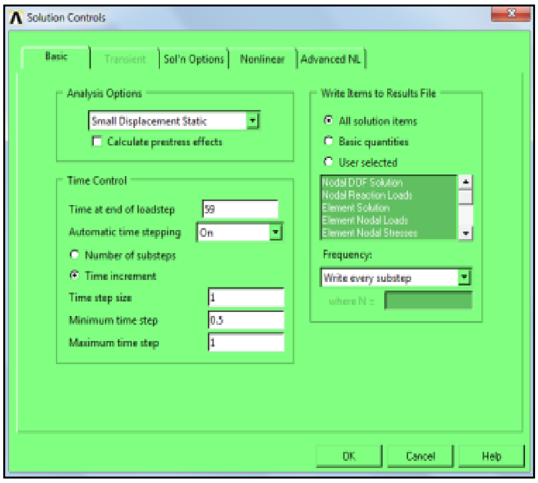
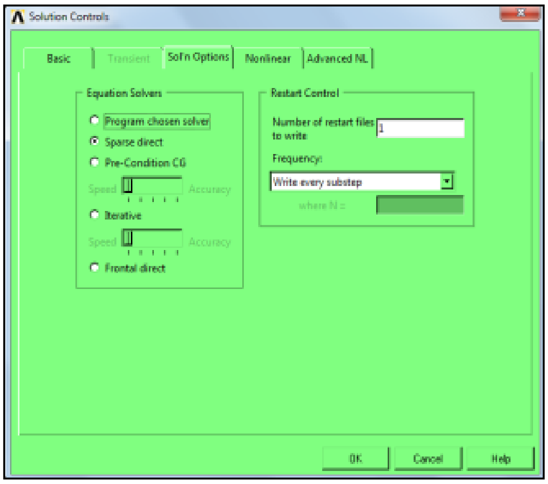


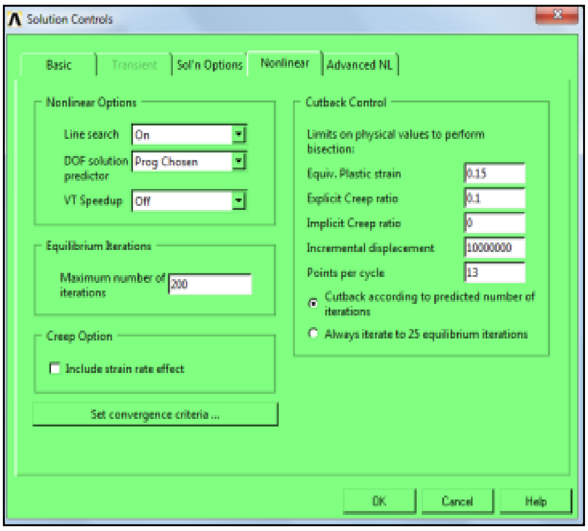
Figure (15). Commands of Analysis's Control



Figure(16). Commands Solver's Type

The analysis was taken as small displacement and static which Performs a linear static analysis ,i.e , a static analysis in which large deformation effects are ignored. The time at the end of the load step refers to the ending load per load step and the total times refers to total applied load. The time step refers to the time increment with maximum and minimum size.

Figure (15) shows the commands of control the ANSYS 's solver; while the commands of the nonlinear algorithm and convergence criteria are shown in Figure (17). The defaults values are set to all values for the nonlinear algorithm as shown in Figure (18).



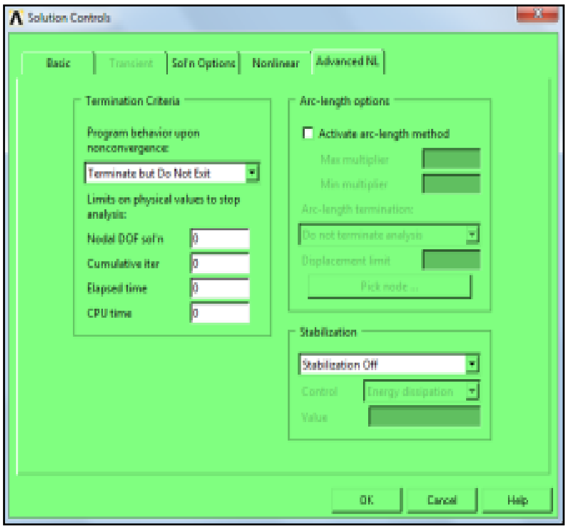


Figure (17). Commands Used for nonlinear **Figure (18). Advanced Nonlinear Control**

5. Discussion

5.1 Load-Midspan Deflection of Flextural Beams

The Y-direction displacements of a specific node in the model mesh that lie in the bottom fiber's location of the axis of symmetry was taken. The data was converted to Excel sheet that represented the deflection with minus sign versus Time steps.

As mention before in this study, the effect of steel fibers effect as smeared reinforcement was taken into consideration. So, the mid-deflections versus loads of plain concrete element, horizontal total lumped steel fiber, vertical total lumped steel fiber, inclined total lumped steel fiber, equally two-way distribution as vertical , horizontal distribution and three-way distribution of vertical, horizontal and inclined distribution were illustrated in Figures (19) to Figure (26). It is obvious that , regardless the uncrack stage ,the plots of load-deflection that predicated by the finite element analysis for equally two-way distribution of steel fibers had a well behavior with the experimental data especially in the over-reinforced cases for control beams and sand-coated CFRP beams .

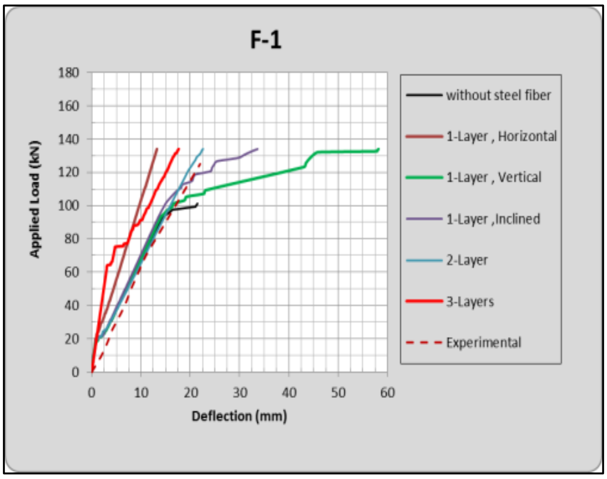


Figure (19). ANSYS Results, mid-deflection versus loads,F-1 Beam

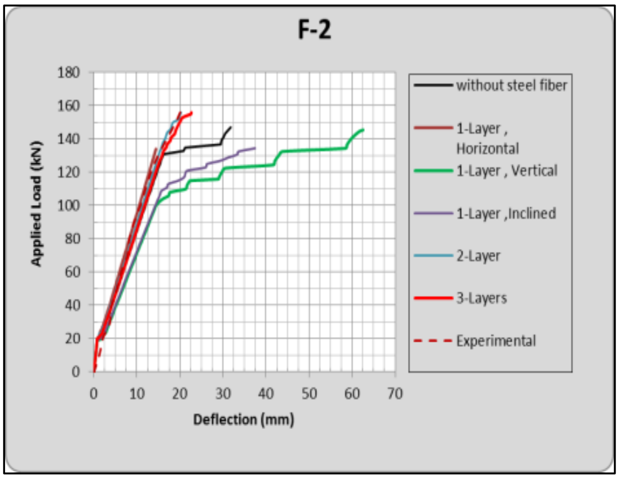


Figure (20). ANSYS Results, mid-deflection versus loads, F-2 Beam

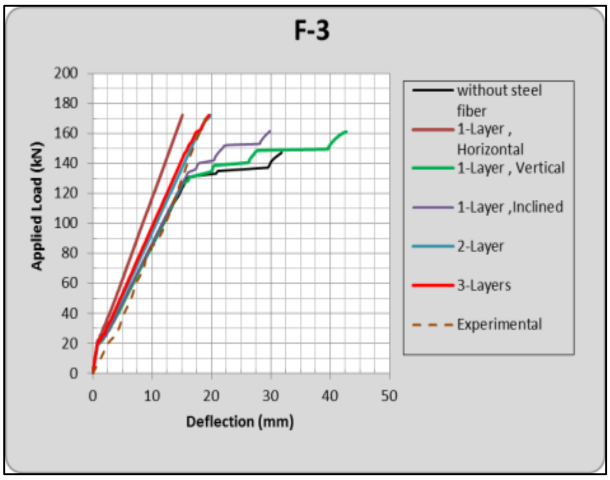


Figure (21). ANSYS Results, mid-deflections versus loads,F-3 Beam

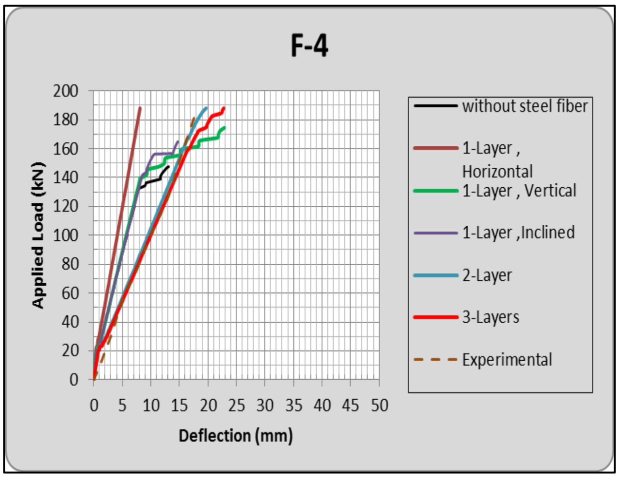


Figure (22). ANSYS Results, mid-deflections versus loads,F-4 Beam

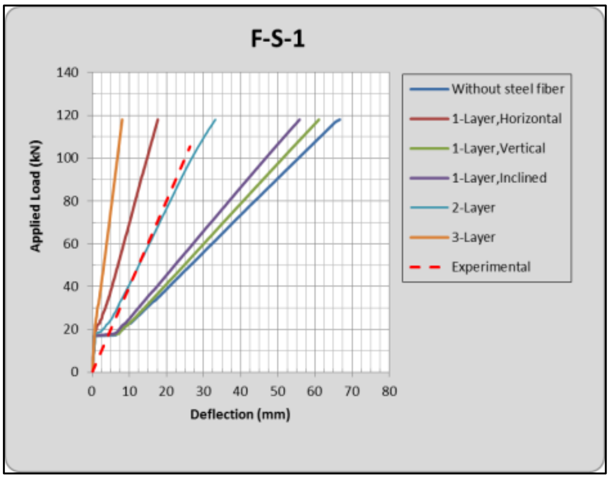


Figure (23). ANSYS Results, mid-deflections versus loads, F-S-1 Beam

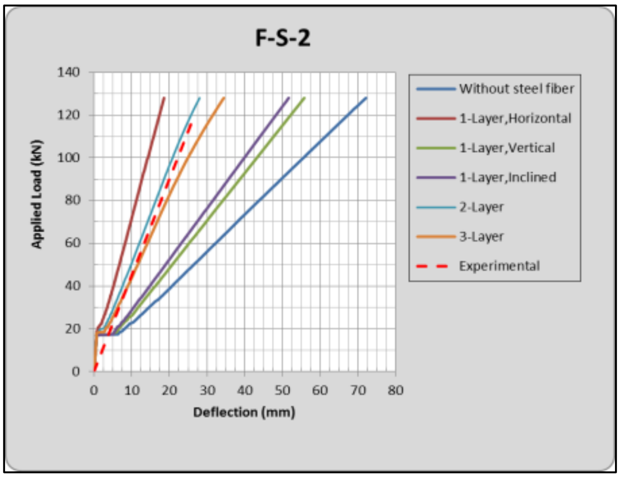


Figure (24). ANSYS Results, mid-deflections versus loads, F-S-2 Beam

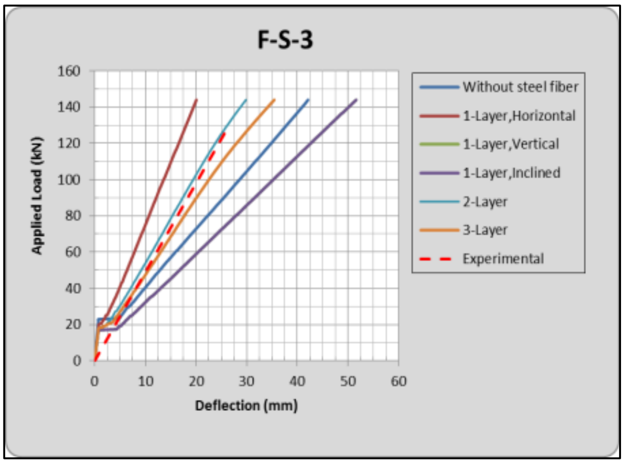


Figure (25). ANSYS Results, mid-deflections versus loads, F-S-3 Beam

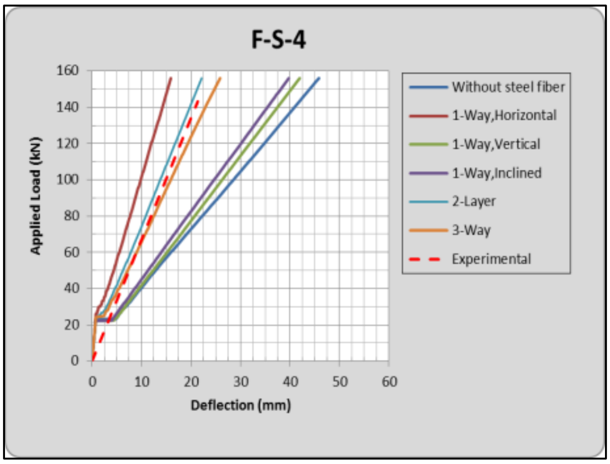


Figure (26). ANSYS Results, mid-deflections versus loads, F-S-4 Beam

6. Conclusions

1. Generally, the using of nonlinear software programming ANSYS 11 can be used for analysis the linear behavior of RPC.
2. The using of Concrete Solid 65 element alone is not preferable in the representation of the reactive powder concrete.
3. The representation of steel fibers as embedded reinforcement equally distribution vertically and horizontally make the results nearest to the experimental data.

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