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BEHAVIOR OF REINFORCED CONCRETE T-BEAMS WITH LARGE WEB OPENINGS FORTIFIED BY REACTIVE POWDER

Rami maytham khadim
Department of Civil Engineering/ College of Engineering of the University of Kufa
Najaf /Iraq, civilrami318@gmail.com

Muhammad Abdel Attiya
Department of Civil Engineering/ College of Engineering of the University of Kufa
Najaf /Iraq, mohammedw.alfatlawi@uokufa.edu.iq

Abstract—

The purpose of this search has presented an experimental and theoretical study of behavior of T-section beams created using regular concrete (normal) and hybrid T-section beams with stratus formed using traditional concrete (normal) and (RPC) - reactive powder concrete. As part of the experimental work, casting and flexure tests were conducted on eight T-section reinforced concrete beams simply-supported at various locations for the large web opening. The RPC layer and the number of openings, are the main variables that this research studies its effect on ultimate loads and cracking loads, along with the mid-span deflection conduct of every NC beam and hybrid with the RPC layer in the tension zone or the compression. In addition to the tension and compression, all tested beams' crack patterns and failure modes had shown and discussed. Through the experimental results obtained from this research, it was found that increasing the layer of RPC will increase ultimate loads (Pu) and give a stiffer load-deflection demeanor. Utilizing RPC for compression was found more effective than applying RPC in tension Where the increase in the ultimate loads of beams containing the RPC in the compression zone and the container on one and two openings, was higher than the ultimate loads of the corresponding beams with normal concrete by (33%,22% respectively)while the increase was In the ultimate loads of beams that contain the RPC in the tensile zone and the container on one and two openings, higher than the ultimate loads of the corresponding beams of normal concrete by (15.15%, 7.4% respectively) and less than the beams that contain RPC in the compressive zone. However, hybrid beams that applied RPC in tension zone had failed to fewer cracks than hybrid beams that applied RPC in compression. The above shows how effectively RPC works in the tension zone to increase the serviceability (controlling cracks) and durability (protecting steel reinforcement) of beams. The increase in the ultimate loads of the beams containing the RPC in the compression and tension zone and the container on one and two openings, was higher than the ultimate loads of the corresponding beams with normal concrete by (36.36%,29.6% respectively). there is generally a good correlation between experimental results for ultimate loads and load-deflection conduct and the outcomes of nonlinear finite element analysis (FEM) performed by the ABAQUS program.

Keywords— Reactive Powder Composite, Layers, Openings, Cracks, Hybrid, ultimate loads, ABAQUS

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About the authors：Rami maytham khadim

Email:

Introduction

The presence of openings in the beam provides many possibilities, including allowing the passage of public utilities and dispensing with the use of low suspended ceilings that reduce effective story heights, but there are also negatives, including that it affects the general structural behavior of the beam, deflection profile, stress flow, and hinge evolution [1, 2]. In beams, transverse openings can be shaped in many different ways, such as rectangular, diamond-shaped, triangular, trapezoidal, or even irregular [1].

Mansur et al. [3], Aykac et al. [4] investigated and tested RC continuous beams with large transverse openings. Test parameters included span number, opening size, and location along the span showed influence on its flexural behavior.

Tanijaya and Hardjito [5] investigatedthe effect of openings on a hybrid reinforced concrete T-section beam's to a cyclic load applied at mid-span.Test outcomes showed that an existing of web openings caused a lower at cracking strength as well as ultimate strength.

Raj and Jeenu [6] and Mohammed [7] hybrid rectangular beams made of conventional concrete (CC) and RPC were studied for their flexural behavior (strength and deformation properties). A few studies looked at the behavior of RC beams with openings and strengthened by RPC. In order to evaluate these impacts on the ultimate strength, mode of failure, strain, and behavior of these beams, this research will examine the extent of the impact of large openings present in the web of reinforced concrete beams strengthened with RPC layers. The number of web openings throughout the span and the positions of the RPC layer are the primary determinants in this study. the outcomes of ultimate strength, load-deflection, failure modes, load-strain, neutral axis depth, and curvature, will be explanation

I. EXPERIMENTAL PROGRAM

A. Materials uesd and Mix Proportion

in this study it used RPC formulated with a substantial proportion of cement (1000 kg/m3), ultrafine sand as aggregate, high-activity pozzolan (densified silica fume), plus superplasticizer (Sika ViscoCrete-5930L) as an agent that reduces water in a wide range and steel fiber. While the normal concrete (NC) was used includes sand, crushed gravel, and normal Portland cement. In Table 1, the specified RPC and concrete mix proportions are listed. The experimental check has been carried out at the Laboratory, Faculty of Engineering Kufa University Iraq. Tests results of mechanical properties: the compressive strength was 78.6MPa for RPC and 36.34MPa for normal concrete (NC) According to (BS EN 12390-3-2002 for cubic samples) [8] ,the modulus of elasticity was 41.43GP for RPC and 31.25GPa for normal concrete (NC) accordance with ASTM (C469/C469M-2014) [9] , the modulus of rupture was 9.86 MPa for RPC and 3.97 MPa for normal concrete (NC) accordance with ASTM C 78-02 [10], and the splitting tensile strength was 8.45 MPa for RPC and 3.471 MPa for normal concrete (NC) accordance with ASTM (C496/C495M-2011) [11]. the Yield Stress for reinforcement bar that used was 397MPa for bar diameter (ϕ4mm),485 MPa for bar diameter (ϕ8mm), 670 MPa for bar diameter (ϕ10mm) the results conform to the Limits of ASTM A615[12]. In order to obtain a good bond between the layers, there should be a period of time about 55-60 minutes until the upper surface of the lower layer becomes rough, and then the layer above it is placed.

Table (1) Mix the proportion of NC and RPC

Concrete	NC	RPC
Cement (C) (kg/m3)	400	1000
Sand (S) (kg/m3)	600	1000
Gravel (G) (kg/m3)	1200	----
Silica fume (SF%) (kg/m3) *	----	150
Super-plasticizer (SP)**(SikaViscoCrete5930L)	----	35
Water (W) (kg/m3)	180	255
Water / cement ratio W/C	0.45	0.255
Steel fiber (SF%) ***	----	78
Mix proportion by weight	1:1.5:2 Cement: sand:gravel	1:1:0.15 Cement: sand:gravel

*Percent of cement weight (15%)

**Percent of binder (cement and silica fume) weight (3%)

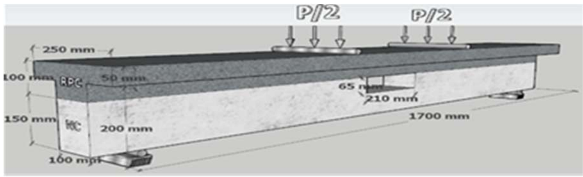
***Percent of mix volume (0.5%)"

B. Samples Preparation

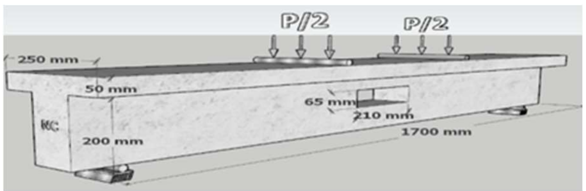
eight simply supported T-section beams with large web openings are being made and tested as part of the experimental program. Under two points of load, these beams are tested with a shear span (av) of 510 mm, where av is the distance between the center of concentrated load (P/2) and the center of support. they are put to the test to see how large web openings affect RC beam behavior and strengthened with RPC to avoid cracking. The dimensions of beams was (1700 mm overall length, 100 mm for web and 250 mm for flange in width, and 200 mm for web and 50 mm for flange in depth). All beams are utilized with a span length of (1500 mm), and the nominal opening dimensions are kept consistent for all beams at (210) mm in length and (65) mm in depth. The distance between two points loads is constant for all beam at (480) mm. All beams are designed with steel reinforcement in accordance with the ACI318-14[13] building code, and for openings, NZS3101-2(2006) [14] is used. The beams are divided into two groups namely Group one with one opening, Group two with two openings The dimensions and reinforcing details of the tested beams are presented in Figs. [2 and 3], whereas Fig. 1 shows the details of the beams, the layers of RPC, and the placements of the openings.

C. Test set-up and Instrumentation

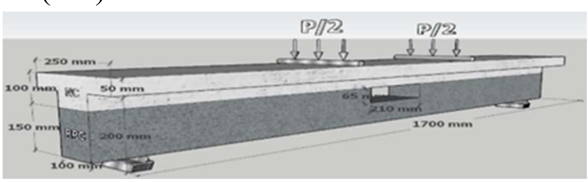
to measure deflection at the center of the beam used a dial gauge with sensitivity's (0.01mm/ division). The crack width was measured using a crack reader for these purposes. The first crack value was measured together with the determination of the applied load, and the crack patterned width measurement process was continued along with the loading stages until the failure stage was reached. all specimens of T-section beam with large openings were tested as simply supported beams exposed to two-point loads with a loading rate of (1 KN/s) using a hydraulic machine with a maximum range capacity of (2000 KN).



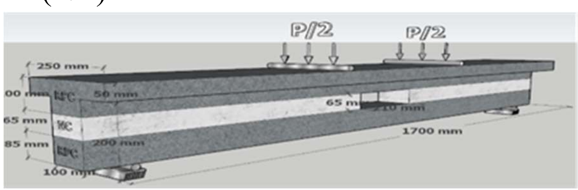
B1(N)



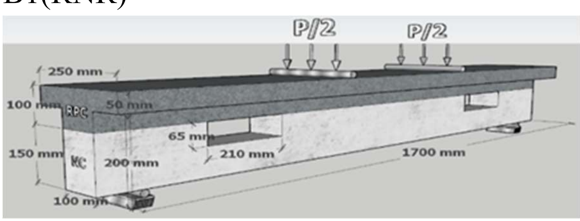
B1(RN)



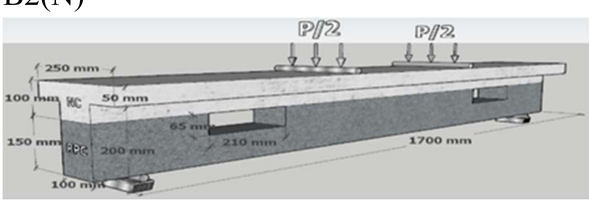
B1(NR)



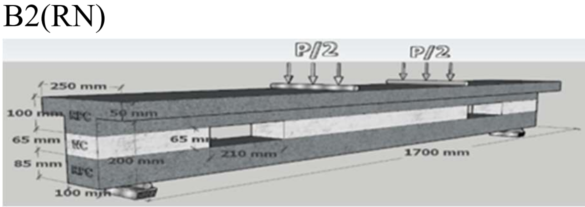
B1(RNR)



B2(N)



B2(RN)



B2(NR)

Figure (1) beams details for layers and opening

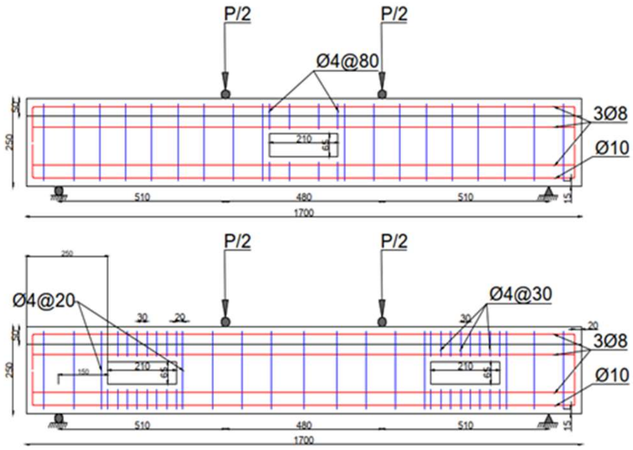


Figure (2) dimension and reinforcement details of tested T-section beams

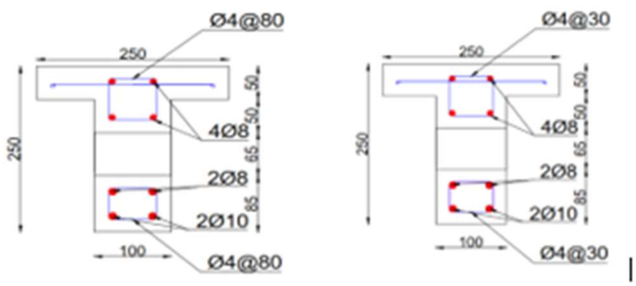


Figure (3) side view dimension and reinforcement details of tested T-section beams

II. RESULTS AND DISCUSSIONS

A. Ultimate loads Results of the Tested Beams

When looking at the data in the table (2,3) ultimate loads (Pu) rise as the number of RPC layers increases. Hybrid beams with RPC in compression have greater ultimate loads than Hybrid beams with RPC in tension. All the foregoing findings show that utilizing RPC in both compression and tension is more effective than utilizing it in either compression or tension alone. Hence, the observed behavior can be explained by the combined influence of stiffness increase for the beams, allowing them to withstand loads that are higher before failing. In conclusion, the discussion above demonstrates that using RPC in compression provides better results than using it in tension, as evidenced by a significant increase in ultimate load due to the compressive strength of RPC being much greater than regular concrete, resulting in compression zone strengthening and increased durability before failure. However, applying RPC in tension can also provide other benefits, which include preventing cracks and protecting steel reinforcing bars. it appears evident that a fact of the presence of an openings (location and number) did not just decrease the beam's ultimate load capacity, but it is also important to understand that it made an alteration to the failure mode, so it happened a transforming from flexural to shear failure.

B. Load-Deflection Curves

a) Influence of RPC Layers on the T-section beams: from the table (2) observed that the maximum mid-span deflections of the hybrid beams with one layer of RPC at the bottom in tension were lower than those of (NC) beams, Because of its greater stiffness, While the maximum deflection of hybrid beams with one layer of RPC at top in compression and the maximum deflection of hybrid beams with two layers of RPC at top and bottom in compression and tension were greater than that of (NC) beams because RPC beams sustained higher ultimate loads and thus can withstand larger deflections (higher energy absorption).

b) Influence of an opening at the T-section beams

It is visible in figures (6) to (11) that if the beam had an opening in the flexural region, the max deflection at the middle span could be considerably larger than when the beam had an opening in the shear region due to the reduction in the ultimate load Table (3) shows the maximum mid-span deflection Opposite to ultimate load while it was observed that the maximum deflection in shear span is less than the maximum mid-span deflection.

Table (2) Influence of RPC Layers in Ultimate Loads and maximum mid-span deflection

Beams	**Pu (KN)**	**Percentage of increase (%)**	**maximum mid-span deflection (mm)**
B1(N)	165	0	15.8
B1(NR)	190	15.15	15.09
B1(RN)	220	33.33	18.11
B1(RNR)	225	36.36	30.43
B2(N)	135	0	9.22
B2(NR)	145	7.4	7.19
B2(RN)	165	22.22	13.72
B2(RNR)	175	29.62	14.58

Table (3) Influence of Number of Opening in Ultimate Loads and maximum mid-span deflection

Beams	**Pu (KN)**	**Percentage of reduction (%)**	**Maximum mid-span deflection (mm)**
B1(N)	165	0	15.8
B2(N)	135	18.18	9.22
B1(RN)	220	0	18.11
B2(RN)	165	25	13.72
B1(NR)	190	0	15.09
B2(NR)	145	23.68	7.19
B1(RNR)	225	0	30.43
B2(RNR)	175	22.22	14.58

C. Failures Modes

For T-section beams with openings, failure methods are those that are described the cracks forming in the locations illustrated in Figure (4,5) [15]. Table (4) are given failure modes of tested T-section beams.

Table (4) Failure modes of the tested beams

Beams	Failure modes of T-section beams
B1(N)	flexure
B2(N)	Shear
B1(RN)	Flexure + crush
B2(RN)	Shear
B1(NR)	Flexure + crush at flange
B2(NR)	Shear
B1(RNR)	flexure
B2(RNR)	shear

FIGURE (4) CRACK PATTERNS WHEN SAMPLES FAIL FOR GROUP ONE

FIGURE (5) CRACK PATTERNS WHEN SAMPLES FAIL FOR GROUP TWO

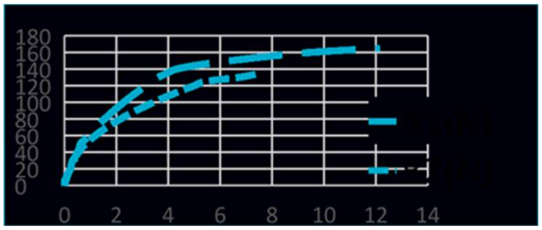


Figure (6) Influence number of opening on load-deflection for (NC) beams at mid span

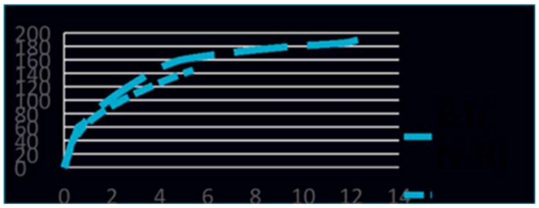


Figure (7) Influence number of opening on load-deflection for (NR) beams at mid span

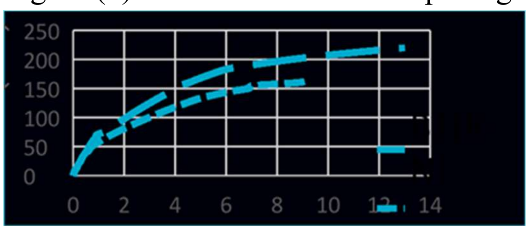


Figure (8) Influence number of opening on load-deflection for (RN) beams at mid span

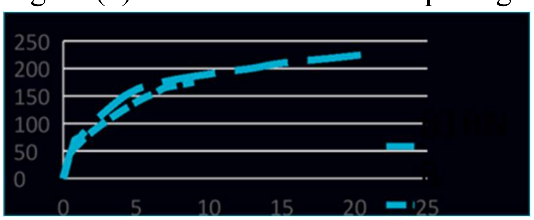


Figure (9) Influence number of opening on load-deflection for (RNR) beams at mid span

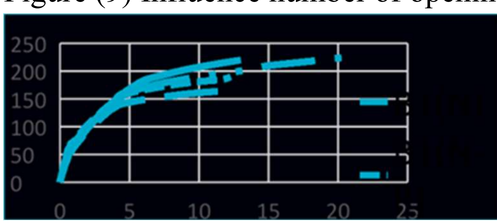


Figure (10) load-deflection curve at mid span for group (1)

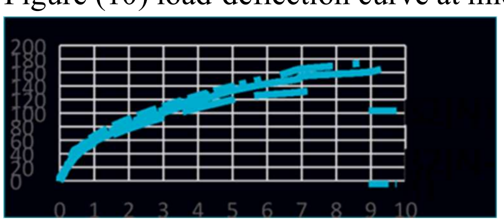


Figure (11) load-deflection curve at mid span for group (2)

D. Finite element method (FEM)

the numerical analysis of the specimens that were tested experimentally was simulated using a nonlinear finite element technique (ABAQUS/CAE 2020 software) (FEM). By comparing the experimental results with those obtained from the numerical study, the correctness and validity of this technique were verified. This comparison was made using load-deflection curves, ultimate load, and mechanisms of failure.

numerical analysis of the specimens that were tested experimentally was simulated using a nonlinear finite element technique (ABAQUS/CAE 2020 software).

Figure (11) Load-Deflection curves of FE vs. EXP. B1(N)

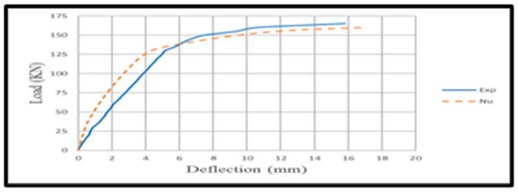


Figure (12) Curves of FE load-deflection vs. EXP. B1(RN)

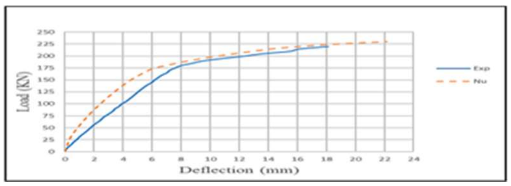


Figure (13) Curves of FE load-deflection vs. EXP.B1(NR)

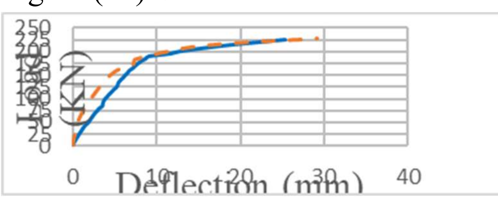


Figure (14) Curves of FE load-deflection vs. EXP.B1(RNR)

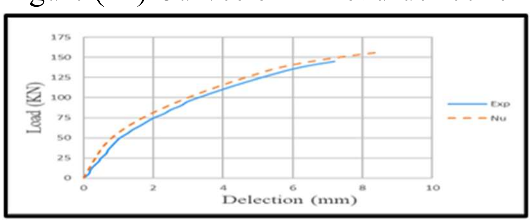


Figure (15) Curves of FE load-deflection vs. EXP.B2(N)

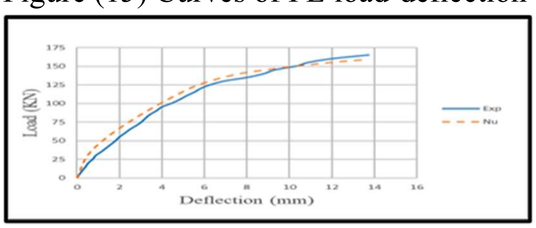


Figure (16) Curves of FE load-deflection vs. EXP.B2(RN)

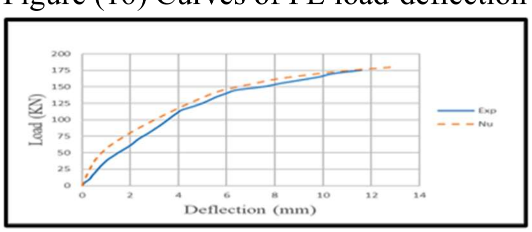


Figure (17) Curves of FE load-deflection vs. EXP.B2(NR)

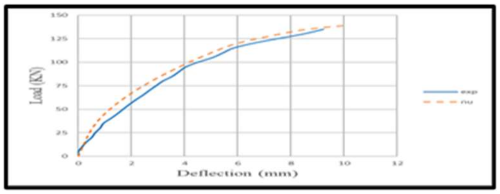
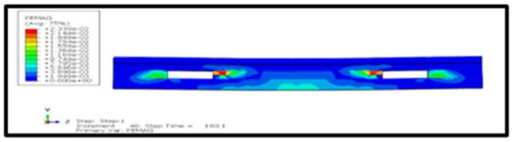
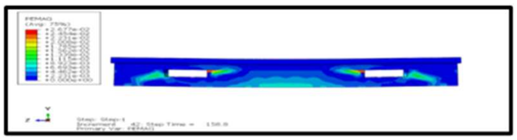


Figure (18) Curves of FE load-deflection vs. EXP.B2(RNR)

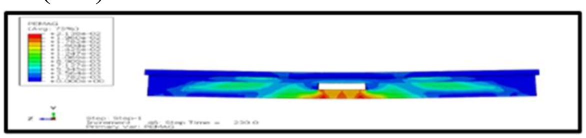
E. Modes of Failure: specimen are shown in Figures(18,19)



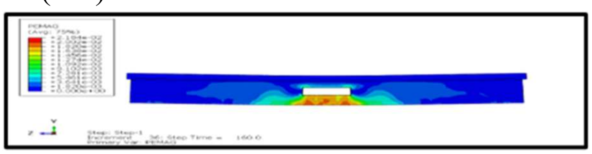
B1(N)



B1(RN)

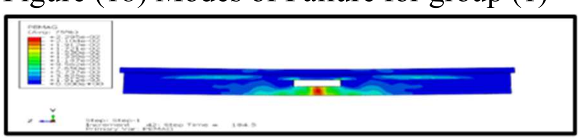


B1(NR)

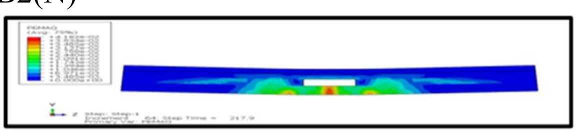


B1(RNR)

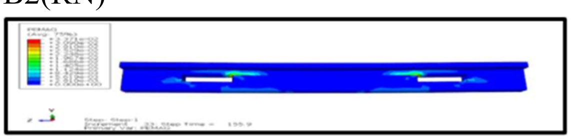
Figure (18) Modes of Failure for group (1)



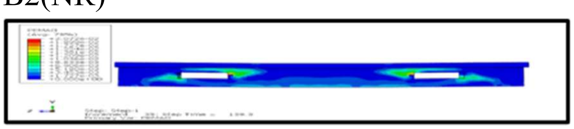
B2(N)



B2(RN)



B2(NR)



B2(RNR)

Figure (19) Modes of Failure for group (2)

CONCLUSION

1. The presence of the opening in a beam of reinforced concrete significantly reduces its stiffness and ultimate strength. Due to stress concentration at the opening corners and a lack of its strengths, a number of cracks occur there as well as diagonal cracks along the upper and lower chords.
2. A reinforced concrete beam's stiffness and ultimate strength are greatly increased when RPC is used, and the amount of cracking that occurs around the opening corners is decreased.
3. Normal beams (NC) with two openings had 18.18 percent and percent less ultimate failure loads than reference beams with one opening.
4. When RPC in a tension Layer with two openings, a beam's ultimate failure load (NR) was 25% lower than those of the reference one opening beam.
5. According to the results, RPC in compression, tension and compression with two openings resulted in 23.68% and 22.22% less ultimate failure loads than the reference beam with one opening.

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