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BEHAVIOUR OF REACTIVE POWDER RECTAINGULAR DEEP BEAM WITH SHEAR ZONE OPENING SUBJECTED TO REPEATED LOAD

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Abstract: This investigation is devoted to study the experimental behavior of six simply supported Reactive Powder Concrete deep beams designed to be failed in shear loaded under two symmetrical point loads and subjected to monotonic and repeated load. Its blended with a same aspect ratio of steel fiber, but different value of the volume fraction which is either 1% or 2%. The tested deep beams had the same overall span of 1200 mm, constant cross section; 115 mm wide and 400 mm overall depth, and reinforced with the same amount of main tension bars (3ϕ20), and a same amount of shear reinforcement $\emptyset 4mm@100$ mm c/c**.** Each deep beam has two typical square opening. There are two different size of the opening; 40 mm and 80 mm. All deep beams have the same; water/cement ratio. Throughout the test operation, the crack patterns were drawn and identified the mode of failure of the tested deep beams. Also the load deflection curves were plotted It was found from observations of this study; a large opening often interrupt the load transfer by concrete struts in deep beams and cause a sharp decrease in strength and serviceability. Also, the presence of the opening in the deep beams decay the ultimate load of the RPC specimens with volume fraction 1% under repeated load by 2.27 times. In particular, it is shown that the presence of steel fiber, along with the RPC, play a crucial role in the transition from flexural to shear dominated failure modes of the beam.

Key words: *Reactive powder, Deep beam, repeated load, shear zone opening*.

تصرف العتبات العميقة المصنوعة من خرسانة المساحيق الفعالة الحاوية على فتحات في منطقة القص والمعرضة الى أحمال متكررة

الخلاصة: يقدم هذا البحث دراسة عملية لسلوك ستة نماذج من العتبات العميقة بأسناد بسيط مصنوعة من خرسانة المساحيق الفعالة صممت على أساس الفشل بحمل القص بتحميل ذات نقطتين ومعرضة الى حمل ثابت وحمل مكرر مسلحة بالياف حديدية بنسبة 1% و2 %. جميع النماذج لها نفس ابعاد المقطع بطول 1200 ملم ومقطع عرضي ثابت مقداره 115 ملم وعمق 400 ملم , أما حديد التسليح فكان متشابهاً لجميع النماذج ويتكون من قضيبي شد (3ϕ20) وحديد تسليح القص $\emptyset 4mm@100$ mm c/c**.** أثنان من النماذج صلدة وبقية النماذج تحتوي على فتحات مربعة قياس 40 ملم و 80 ملم كل النماذج لها نفس نسبة الماء / سمنت ومن خلال نتائج هذه الدراسة تم رسم نمط التشققات وشكل الفشل وكذلك منحنيات التشوه . تشير النتائج الاولية الى أن الفتحات الكبيرة تعترض انتقال الحمل بواسطة دعامة الخرسانة وتسبب نقصان كبير في المقاومة وكذلك وجود الفتحات بالعتبات العميقة يقلل الحمل الاقصى للنماذج ذات نسبة 1% الياف حديدية تحت حمل متكرر بمقدار 2.27 مرة. وبشكل خاص يمكن ملاحظة وجود الالياف الحديدية في خرسانة المساحيق الفعالة يلعب دور كبير في تغيير نمط الفشل من فشل انحناء الى فشل قص.

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1. Introduction

The development in concrete manufacturing production not perceptible compare with the other engineering scientific, however researchers working hard to investigate the behavior of construction buildings members using suitable kind of materials that match a complicated design.

The use of reactive powder concrete has increased considerably during the last decade, due to the high ductility of RPC compared to conventional concrete structures allowing larger elastic deflections, considered a good anti-seismic characteristics reducing cross sections, and providing higher energy absorption [1].

Reinforced concrete deep beams are used as load distributing structural members such as transfer girders, pile caps, foundation walls, and offshore structures.

Almost openings implemented in concrete structural building to achieve multi issues related to the requirements of architectural construction design. Heavy reinforcement ratio in slender beam considered openings obstruction, therefore using deep beam is a good solution especially with Reactive powder concrete. [2]

Many structure subjected to Cyclic load such as Bridge members, offshore structures and vibrating machinery members. This study focuses on the impact of the using repeated load on the reactive powder concrete deep beams with different size of opening.

2. Experimental Program

According to the ACI code Provisions for shear , deep beams are members with length of clear span measured face to face of supports (L) not exceeding four times total depth (h), or region of beams with concentrated loads within a distance (a) two times the total depth measured from the support, that is loaded on one face and supported on the opposite face[2], as shown in the Figure (1).

$L \leq 4h$ or $a \leq 2h$

Loaded on one face and supported on the opposite face.

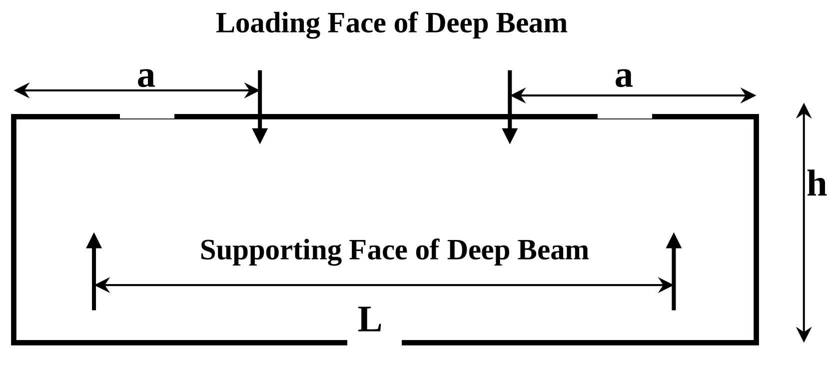


Figure 1. Provisions of deep beams according to ACI code for shear [3]

Based on previous researchers, an experimental program was planned and executed to investigate the behavior of simply supported concrete deep beams tested under repeated loading, subjected to two-point of loading until fail in shear. Includes 6 reinforced concrete deep beams with a same dimension; overall length of 1200 mm, width of 115 mm, and a height of 400 mm, with a constant shear span to depth ratio (a/d=1). For all tested beams, the same amount and type of reinforcement details, as shown in the Plate (1).

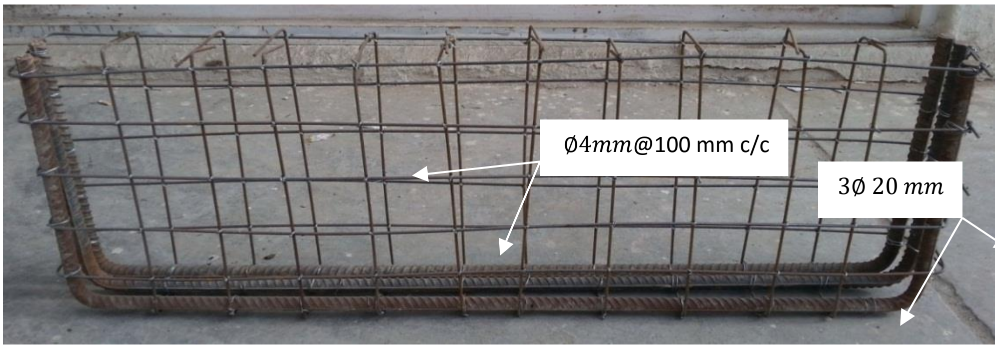


Plate 1. Deep Beam Reinforcement Details

The first specimen was a control specimens, which is tested under monotonic loading and casted as a solid deep beam without openings. While the other five specimens of deep beams tested under repeated loading, with two types of square openings with dimensions, 40 mm and 80 mm, as shown in the Table (1). The silica fume percentage used in this study is 0.25 for all RPC mixes and water/Cement Ratio=0.2. A three types specimen (cubes, cylinders and prisms) were taken for each mix used in casting deep beams. The properties investigated herein includes; compressive strength, flexural tensile strength, splitting tensile strength, and modulus of elasticity.

Table 1. Parameters of Reactive Powder Reinforced Concrete Deep Beams

No.	Beam Designation	Steel Fiber	Opening dimensions	Type of Loading
1	MO-R-S-1%*	1%	Solid	Monotonic
2	RT-R-S-1%	1%	Solid	Repeating
3	RT-R-40-1%	1%	40 mm	Repeating
4	RT-R-80-1%	1%	80 mm	Repeating
5	RT-R-40-2%	2%	40 mm	Repeating
6	RT-R-80-2%	2%	80 mm	Repeating

*MO=Monotonic Load, R=Reactive Powder Concrete. S=Solid (No opening).
RT=Repeating Load

The variable parameters in this study are;

1. Amount of steel fiber content ratios 1% and 2%;
2. Opening dimensions 40 mm and 80 mm;
3. Type of Loading, monotonic and repeated load. The operation of mixing, casting,

curing, and testing of deep beam was conducted in the construction laboratory of the Civil Engineering Department, faculty of engineering / Al-Mustansirya University.

3. Properties of Materials

3.1 Cement

Ordinary Portland Cement (OPC), (Type I) Tasluja-Bazian, Sulymania-Iraq was used for all mixes. The physical properties and chemical composition of the used cement is shown in Table (2) and Table (3) respectively. The results conform to the [Iraqi specifications No.5/1984] [3].

Table 2. Physical Properties of the Cement Used in This Study

Physical properties	Test results	Limit of Iraq specification No.5/1984
Specific surface area, cm^2/gm	2650	≥ 2300
Setting time (vicat's apparatus)		
Initial setting, hrs: min	2:30	≥ 0:45
Final setting ,hrs :min	4:10	≤ 10:0
Compressive strength		
3days, MPa	17	≥ 15
7days, MPa	24.7	≥ 23

Table 3. Chemical Composition and Main Compounds of Cement Used in This study*

Oxide composition	Abbreviation	Content %	Limits of Iraqi specification No.5/1984
Lime	CaO	60.60	-
Silica	SiO_2	19.60	-
Alumina	Al_2O_3	5.52	-
Iron Oxide	Fe_2O_3	3.11	-
Sulfate	SO_3	2.27	≤2.8%
Magnesia	Mg O	1.80	≤5.0%
Loss on ignition	L.O.I	1.60	≤4.0%
Insoluble residue	I.R.	1.10	≤1.5%
Lime saturation factor	L.S.F	0.93	0.66-1.02
Main Compounds (Bogue's equations)			
Tricalcium Aluminate	C_3A	9.37	-

* Chemical and physical tests were carried out in the National Center for Construction Laboratories and Researches (NCCLR).

3.2 Fine Aggregate

Al-Ekhaider natural sand of 4.75mm maximum size, was used as fine aggregate. For the RPC mixes, a very fine sand with a maximum size of 600μm was used. This sand was separated by sieving, its grading satisfied the fine grading in accordance with the Iraqi Specification No.45/1984. [4] Table (4), (5) illustrate the sieve analysis of the separated fine sand and chemical properties used in RPC mixes.

3.3 Silica Fume

The silica fume used in this study was imported by the Sika Company. Silica fume has been used as a mineral admixture added to the mixtures, the chemical composition and properties of the used silica fume conforms to the chemical and physical requirements of [ASTM C1240-03] [5], as shown in Tables (6) and (7) respectively.

Table 5. Chemical Properties of Fine Aggregate

Physical properties	Test results	Limits of Iraqi specification No.45/1984
Specific gravity	2.7	–
Sulfate content	0.09%	≤0.5%
Absorption	0.74%	–

Table 6. Chemical Composition of the Used Micro Silica Fume*

Composition	Content percentage ratio %	Limit of specification requirements ASTM C1240-03
SiO_2	95.94	≥85.0
Moisture content, Max.	0.8	≤3.0
Loss on ignition, Max.	2.5	≤6.0

*Tests were carried out at the National Center of Geological Survey and Mining

3.4 Steel Reinforcement

Six reinforced concrete deep beams were casted and tested in this study; all the specimens have the similar arrangements of reinforcement detail as shown in the Fig. (2).

The test results indicate that the adopted steel reinforcing bars conformed to [ASTM A615-86] [6], as shown in Table (8).

Table 7. Physical Composition of the Used Micro Silica Fume*

Properties	Content percentage ratio %	Limit of specification requirements ASTM C1240-03
Percent retained on 43μm (No.325) sieve analysis	7	≤10
Accelerated pozzolonic strength activity index with Portland cement at 7 days min percent of control	197	≥105
Specific surface min, m^2/g	2.0	≥1.5

*Tests were carried out at the National Center of Geological Survey and Mining.

Table 8. Specifications and Test Results of Steel Reinforcement

Nominal Diameter (mm)	Yield Strength (fy) (MPa)	Ultimate Tensile Strength* (fu) (MPa)	Assumed Modulus of Elasticity (GPa) [ACI 318-M95]	Notes
4	540	680	200	Vertical and horizontal Shear reinforcement
20	500	730	200	Flexural reinforcement

*Each value is an average of three specimens (length of each 500 mm)

**Assumed

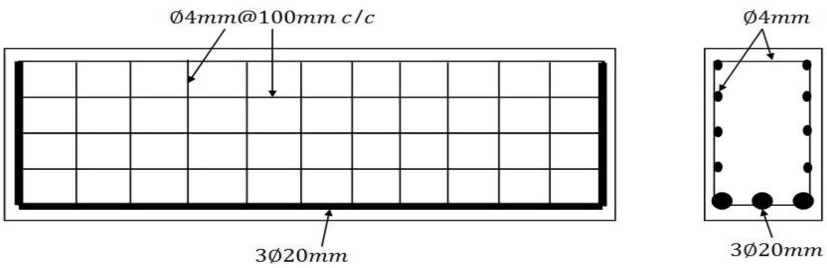


Figure 2. Reinforcement Used in This Study

3.5 Steel Fibers

Throughout this work, a glued bundles hooked ends mild carbon steel fibers were used, with a volume fraction of (Vf =1.0% and 2%). The properties of the steel fibers is presented in Table (9).

Table 9. Properties of Steel Fiber*

Descriptions	Properties
Description (Type of steel fiber)	Straight
Length of fiber (mm)	30
Diameter of Fiber (mm)	0.375
Tensile strength (MPa)	1800
Modulus of Elasticity (GPa)	200
Density (kg/m^3)	7800
Cross section	Round
Aspect ratio (Length/Diameter)	80
Commercial name	SIKA
Origin of manufacturer	Turkey
Configuration	Hooked ends
Ultimate strength	2000 MPa
Strain at proportion limit	5650 x 10^{-6}
Poisson's ratio	0.28
Steel fiber shape	

* supplied by the manufacturer

3.6 High Range Water Reducing Admixture (HRWRA)

High range water reducing chemical admixtures added to the mix to balance the requirements of both workability of fresh concrete and strength of hardened concrete [Ramachandran, 1995] [7]. These chemicals are known as super plasticizers. A super plasticizer used throughout this work is a third generation of super plasticizer which is known commercially as Glenium 51, free from chlorides and it is compatible with all Portland cements that meet recognized international standards and complies with [ASTM C494-86] [8], as described in Table (10).

Table 10. Properties of Super plasticizer*

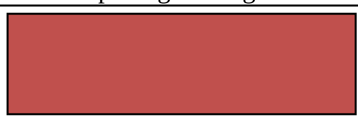
Properties	Description
Commercial name	Glenium 51
Form	Viscous liquid
Color	Light brown
Relative density	1.08 – 1.15 g/cm3 @ 25° C
PH	6.6
Viscosity	128± 30 cps @ 20° C
Transport	Not classified as dangerous
Labeling	Not hazard label required
Chlorides	Free from chlorides
Subsidiary effect	Increased early and ultimate compressive strength
Chemical composition	Sulphonated melamine and naphthalene formaldehyde condensates

*Supplied by the manufacturer.

4. Web Opening Details

To study the effect of openings in deep beams, two solid beams are casted without web opening. The other beams with two symmetry dimensions of web openings were considered. The details of openings and configurations of the web openings were shown in Table (11).

Table 11. Details of Web Openings and Configurations

Beam Designation	Details of Opening	Web openings configurations
MO-R-S-1%	Solid	
RT-R-S-1%	Solid	
RT-R-40-1%	40 mm, square	

RT-R-80-1%	80 mm, square	
RT-R-40-2%	40 mm, square	
RT-R-80-2%	80 mm, square	

5. RPC Mix Design

The amount of cement of the RPC is as high as 900-1000 Kg/m^3 [9]. Amount of cement used in this study was 900 Kg/m^3. The ratio of fine sand content to cement content in RPC mixes is usually taken as (1:1) [10]. The quantity of micro silica selected is 0.25 of the cement content [10]. Table (12) shows the materials proportioning in the RPC mixes.

Table 12. RPC mix design

Material	Mass (kg/m^3)	% of Cement
Cement	900	-----
Fine sand	900	100
Micro Silica	225	25
Water	180	20
HRWRA, 5% of binder	56.25	6.25

6. Testing Set Up

All beams have been tested using a Universal Testing Machine model (8551 MFL system); The specimens have been placed on the machine at free supported roller at one end and hinged from another end using two soft handle clamps in one side to achieve the hinged situation. Each beam was loaded directly at the top face with two equal symmetry concentrated loads. A bearing plate of 110×40×25mm dimension, at the points of load application

were used to avoid local bearing failure during testing, a thin wooden patches are inserted between the concrete and points of loads to avoid local crushing of concrete, as shown in Plate (2). The vertical deflections values are measured at deep beam mid-span was by using a digital dial gage of (0.01mm/div.) accuracy and (30mm) capacity at every load stage. The reference beams (MO-R-S-1%) were tested under static loads in successive increments up to failure. The other 5 beams were tested under repeated load with 2 cycles of loading. In monotonic test, deep beam was loaded incrementally up to failure. While in repeated loading test, cycles of repeated loading reach the required amplitude then return to zero, after 2 cycles. The first cycle load applied up to 22% of the monotonic failed load applied to the specimen, and the second cycle load applied is up to 35% of the monotonic failed load applied to the specimen. If the specimen does not fail in the specific load required of the second cycle, the loading continues to increase until failure.

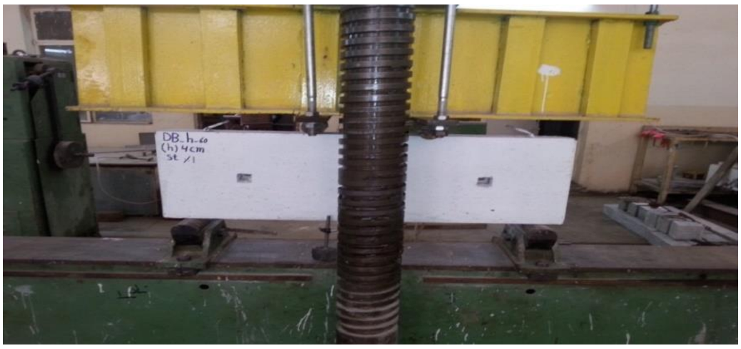


Plate 2. Testing set up

8. Results and discussion

8.1 Mechanical properties of RPC Specimens

The average results value of the mechanical properties of RPC specimen's tests obtained from the experimental work shown in Table (13).

Table 13. Average Compressive Strength and correlation between Cubes and Cylinders

Sample No.	Steel Fiber %	Average* Compressive Strength of Cube f_{cu} (MPa)	Average Compressive Strength of Cylinder f_c' (MPa)	Average splitting tensile strength (fct) (MPa)	Average flexural tensile strength (fr) (MPa	Measured Static Modulus of Elasticity Eq.(3.6)(GPa)
MO-R-S-1%	1%	115	105	5.05	6.75	33.85
RT-R-S-1%	1%	114	106	6.23	7.34	
RT-R-40-1%	1%	112	104	5.91	7.90	
RT-R-80-1%	1%	118	109	5.65	7.50	
Average		114.75	106	5.71	7.40	
RT-R-40-2%	2%	125	115	6.50	7.50	35.76
RT-R-80-2%	2%	128	117	6.75	8.10	
Average		126.5	116	6.63	7.80	

From above table we obtained:

1. The RPC; compressive strength with Vf=2% is greater than compressive strength with Vf=1% by 10% and 9.4% for the compressive strength of cube (fcu) and cylinder (f'c), respectively.
2. The average value of the measured RPC splitting tensile strength (fct), flexural tensile strength (fr) , modulus of elasticity with Vf=2% is greater than its corresponding values with Vf=1% by 16%, 5.4%, 9.5% Sequentially.

8.2. Load-Deflection Behavior

The load-deflection results value has been reported for each reinforced concrete deep beams, as shown in the Table (14). The following observation have been found:

1. The maximum value of the ultimate load (1750 kN), exhibited from the solid deep beam MO-R-S-1% with Vf=1%, under monotonic load. While, the minimum value of the ultimate load (1100 kN), marked from the deep beam RT-R-80-1% with 80 mm opening with Vf=1%, under repeated load. The difference between them is 650 kN.
2. The maximum value of the ultimate deflection is 6.8 mm appeared from the deep beam RT-R-80-1% with Vf=1%, under repeated load. While, the minimum value of the ultimate deflection is 4.41 mm appeared from the solid deep beam MO-R-S-1% with Vf=1%, under repeated load. The difference between them is 2.39 mm.

Table 14. Load, deflection, and first crack values

Beam Designation	1st cycle		2nd cycle		3rd cycle		First crack load kN	First crack cycle
	Ultimate load kN	Ultimate deflection mm	Ultimate load kN	Ultimate deflection mm	Ultimate load kN	Ultimate deflection mm		
MO-R-S-1%	-	-	-	-	1750	4.41	645	3rd
RT-R-S-1%	380	1.02	610	1.76	1620	5.85	600	3rd
RT-R-40-1%	300	0.89	500	1.66	1340	6.2	550	3rd
RT-R-80-1%	230	0.93	370	1.52	1100	6.8	420	3rd
RT-R-40-2%	350	0.9	560	1.67	1465	5.97	585	3rd
RT-R-80-2%	270	0.9	430	1.47	1220	6.15	480	3rd

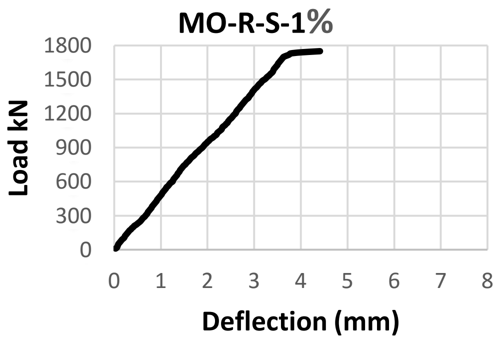


Figure 3. Load-deflection curve for monotonic load RPC, solid, Vf=1%

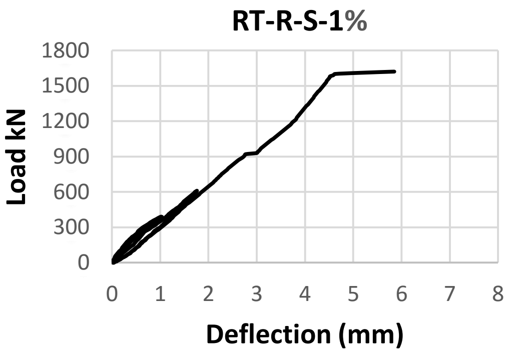


Figure 4. Load-deflection curve for repeated load RPC, solid, Vf=1%

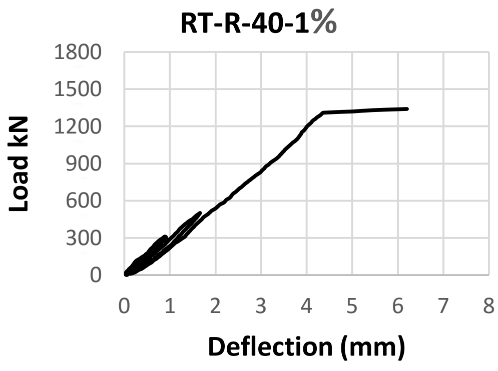


Figure 5. Load-deflection curve for repeated load, 40mm opening, Vf=1%

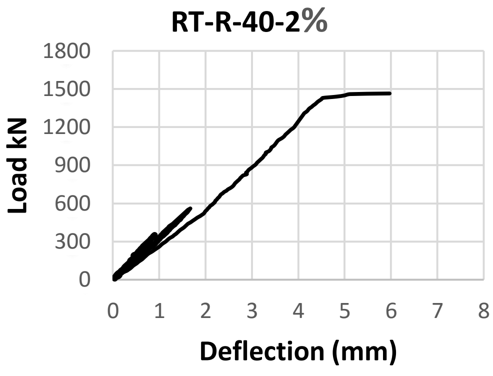


Figure 6. Load-deflection curve for repeated load, 40mm opening, Vf=2%

Also, the percentage of the deflection value at ultimate load for each RPC deep beam to the deflection value at ultimate load for the reference specimen MO-R-S-1% varies between (132.7 and 154.2), as shown in Table (15). It is clear that deep beam RT-R-80-1% gained the maximum percentage which is considered the more ductile deep beam of the RPC specimens, as shown in the Figure (9).

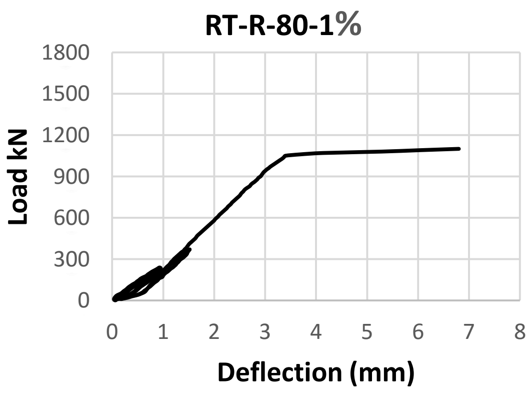


Figure 7. Load-deflection curve for repeated load, 80mm opening, Vf=1%

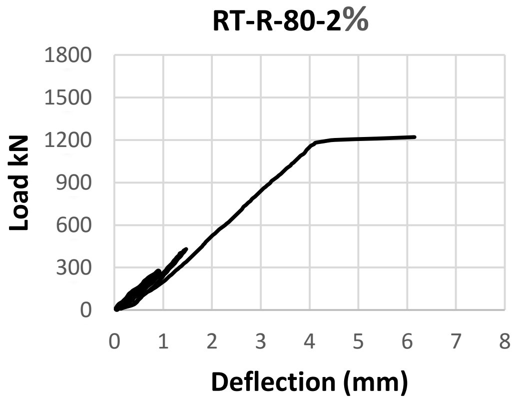


Figure 8. Load-deflection curve for repeated load, 80mm opening, Vf=2%

Table 15. Ratio of the deflection values of RPC Beams at ultimate load with respect to the Reference

Beam Designation	Ultimate deflection Δ mm	Δ/ΔR %
MO-R-S-1%*	4.41	100
RT-R-S-1%	5.85	132.7
RT-R-40-1%	6.2	140.6
RT-R-80-1%	6.8	154.2
RT-R-40-2%	5.97	135.4
RT-R-80-2%	6.15	139.5

* Reference RPC deep beam.

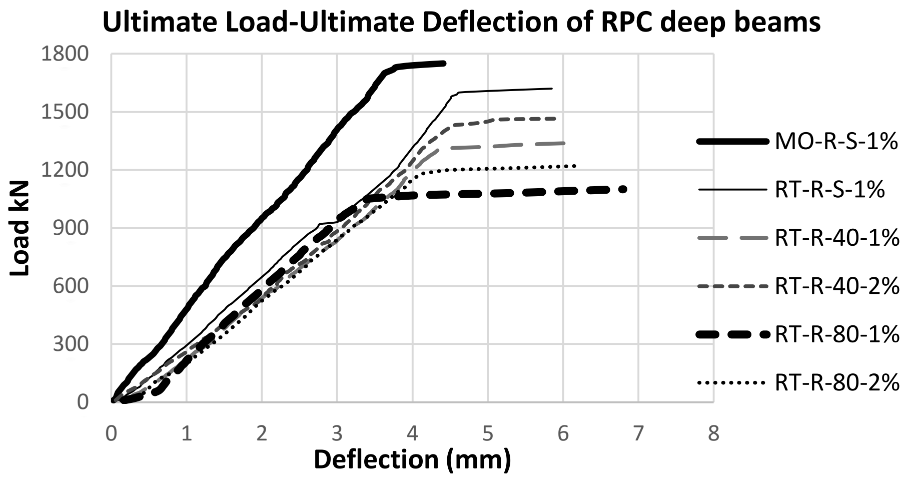


Figure 9. Ultimate Load-Ultimate Deflection of RPC deep beams.

8.3 First Shear Cracks

From the Figure shown, the following observation can be detailed:

1. The maximum load value of first crack (645 kN) gained by specimen MO-R-S-1%, while the minimum load value of first crack (420 kN) gained by specimen RT-R-80-1%.
2. For the RPC specimens; the maximum deflection value (2.12 mm) presented by specimen RT-R-40-2%, while the minimum deflection value (1.32 mm) of first crack presented by specimen MO-R-S-1%.

It obvious to understand from this context that the first cycle of the load history considered as a first stage of load-deflection which is the elastic stage behavior, as shown in the Figure (10). The slope of load-deflection curve, almost steady and there were no drastic changes in the behavior. which starts from zero load point until reaching the first cracking load point, or the specified amplitude load required. this part having a relatively steep slope than the second cycle history load, which means that the deep beams at this stage are of relatively higher flexural rigidity. The second cycle load-deflection curve is relatively linear with less steep slope than the first stage and the deep beams at this stage have less rigidity due to the development of flexural cracks, as shown in the Figure (11).

Table 16. Load and Deflection Values at First Shear Crack

Beam Designation	Vf%	Dimension of Openings (mm)	First Shear Crack Load kN	Deflection (mm)	First crack cycle
MO-R-S-1%	1%	Solid	645	1.32	-
RT-R-S-1%	1%	Solid	600	1.86	2nd
RT-R-40-1%	1%	40	550	2.04	2nd
RT-R-80-1%	1%	80	420	1.54	2nd
RT-R-40-2%	2%	40	585	2.12	2nd
RT-R-80-2%	2%	80	480	1.87	2nd

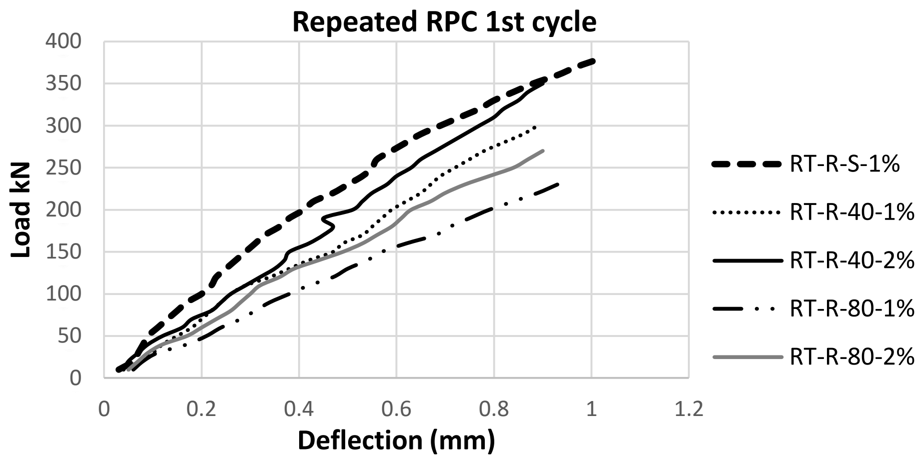


Figure 10. Load-deflection curve for repeated load 1^{st} cycle RPC

For repeated loading tests, the behavior of load-deflection curve during the first cycle is similar that occurred in the monotonic test until the load reached the required amplitude. The cracks that opened during the first cycle as the load level is increased, then closed at the unloading part of the cycle. For other subsequent cycles, the same cracks that appeared during the loading opened and closed during the lifting load. After 2 cycles, if the specimens did not fail, the loading was allowed to increase up to failure.

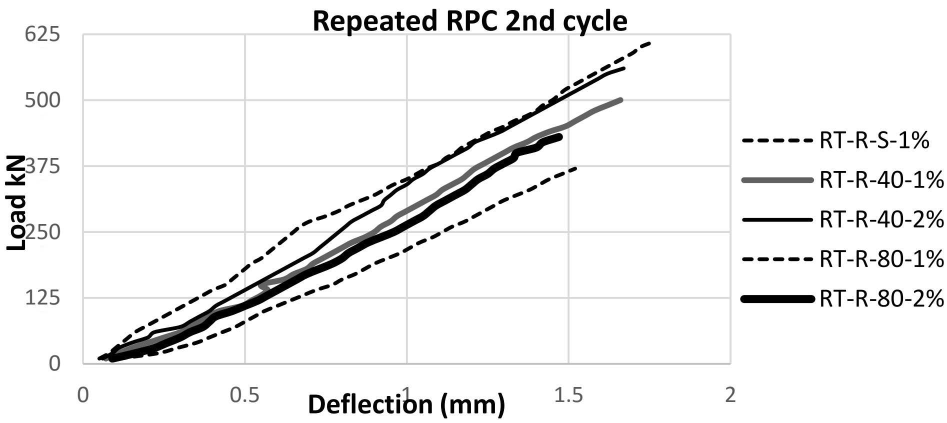


Figure 11. Load-deflection curve for repeated load 2^{nd} cycle, RPC

8.4. Effect of Steel Fiber

The inclusion of steel fibers leads to a considerable increase in tensile strength (direct, splitting and flexural). Increasing the volume fraction of fibers resulted in an increase in the direct tensile strength. The increase in the steel fibers volume fraction content improved the load-deflection behavior and consequently gave larger ductility and fracture toughness of RPC. Addition of steel fibers to RPC was found to change the brittle nature of the non-fibrous matrix to a composite mass with a plastic behavior after first crack. Also the presence of steel fibers gave a longer plastic range of the load-deflection behavior with higher peak load, as shown in the Figure (12) and Figure (13).

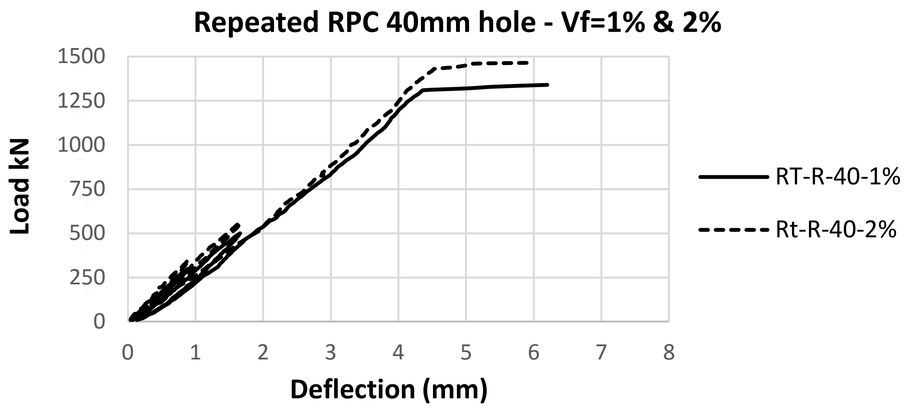


Figure 12. Effect of Vf 1% on Load-deflection curve for Repeated Load 40mm opening.

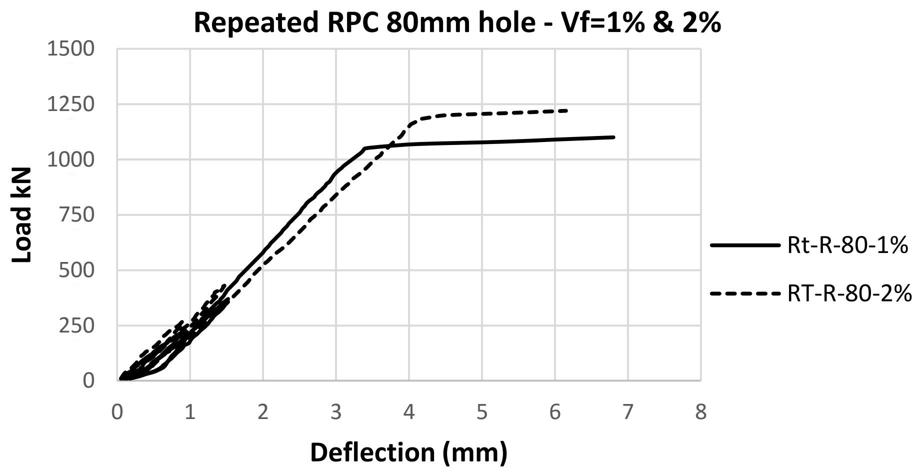


Figure 13. Effect of Vf% on Load-deflection curve for Repeated Load 80mm opening

8.5. Effect of Opening on the Behavior of Deep Beam

The size of the openings in the specimens were selected to interfere with the direct load paths that could potentially form a crack between the loading point and the supports.

In comparison the effect of presence or absence of the opening on the ultimate load of the tested deep beams (RT-R-S-1% , RT-R-40-1%, RT-R-80-1%, RT-R-40-2%, RT-R-80-2%), the following observations can be noted:

1. The ultimate load of the specimen RT-R-S-1% is greater than the ultimate load of the specimen RT-R-40-1% by 20.8%.
2. The ultimate load of the specimen RT-R-S-1% is greater than the ultimate load of the specimen RT-R-80-1% by 47.2%.
3. The presence of opening in the deep beams decay the ultimate load of the RPC specimens with volume fraction 1% under repeated load by 2.27 times.
4. The ultimate load of the specimen RT-R-40-1% is greater than the ultimate load of the specimen RT-R-80-1% by 21.8%.

5. The ultimate load of the specimen RT-R-40-2% is greater than the ultimate load of the specimen RT-R-80-2% by 20%.
6. - The ultimate deflection of the specimen RT-R-80-1% is greater than the ultimate deflection of the specimen RT-R-40-1% by 9.6%.
7. The ultimate deflection of the specimen RT-R-80-2% is greater than the ultimate deflection of the specimen RT-R-40-2% by 3%.

8.6. Effect of Repeated Load on Deflection

In comparison the effect of type of loading on the ultimate load of the tested solid deep beams having the same type of concrete, same volume fraction, for the specimens (MO-R-S-1%, RT-R-S-1%) the following observations can be noted:

1. The ultimate load of the specimen MO-R-S-1% is greater than the ultimate load of the specimen RT-R-S-1% by 8%.
2. The ultimate deflection of the specimen MO-R-S-1% is greater than the ultimate deflection of the specimen RT-R-S-1% by 25%.

8.7. Crack Pattern and modes of failure

The control deep beams failed in shear. At low load levels, the beams behaved in an elastic manner, defects in their structure and cracks did not appear at all regions and the deflections were small. Then; there were some flexural cracks along the deep beam bottom face. When the load was increased, some flexural cracks at the middle region of the shear span changed their direction and propagated toward the loading point (diagonal crack which is usually known as flexural-shear crack). With increasing load additional shear cracks were formed through the shear span, widened and propagated until failure occurred because of the formation of a major wide diagonal crack along the line joining the edge steel blocks at the support and loading positions (strut of the deep beam). Plate (3) through Plate (8), discerned the general mode of failure and crack pattern for each deep beam

There is a diagonal stress concentration at the two corners of the openings, the first corner being located near the load point and the other diagonally opposite to it. In all beams, the first crack was a sudden inclined tension crack originating from the corners of the opening. When the load was increased, the lower inclined crack

Plate 3. MO-R-S-1% Deep Beam

Plate 4. RT-R-S-1% Deep Beam

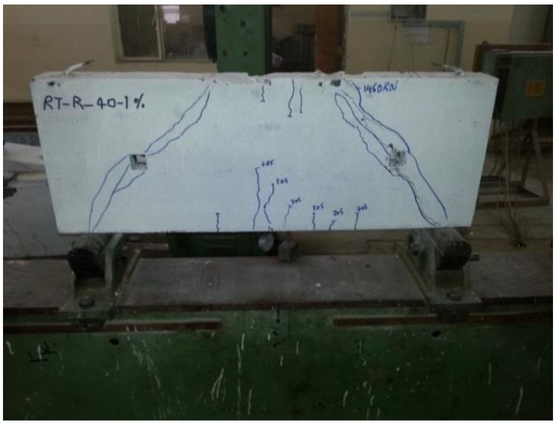


Plate 5. RT-R-40-1% Deep Beam

Plate 6. RT-R-80-1% Deep Beam

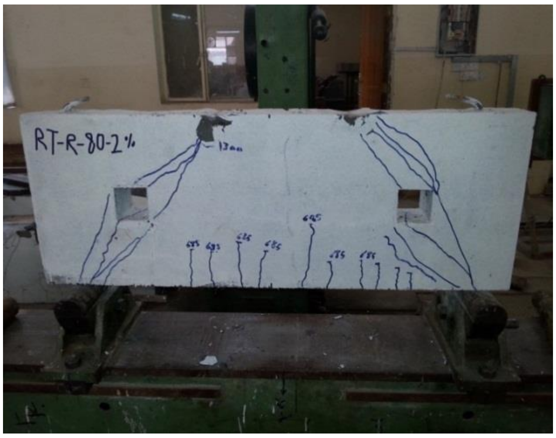


Plate 7. RT-R-40-2% Deep Beam

Plate 8. RT-R-80-2% Deep Beam

propagated towards the edge of the support bearing plate, while the upper crack propagated upwards to the area just below the loading point and stopped there. The latter is due to the influence of the compressive stress in that region. Vertical flexural cracks also appeared at the midspan of the beam. Finally, the beam failed by diagonal tension, causing a clean and sudden fracture. It is mainly a line joining the edge of the support or loading plates to the corner of the opening. For the beams with openings size 80 mm, which are close to their vertical edges failure was caused by a crack originating from the edge of the beam to the outer corner of the large opening. For the solid beam, the fracture was along the natural load path. Very high shears combine with high flexural stresses near the support, giving rise to critical diagonal tensions in this region.

The crushing of concrete at top and bottom surface of the deep beam near the fixed end became more severe, especially at the deep beams RT-R-80-2% and RT-R-80-1%

The crack patterns of the specimens with openings, demonstrate that the mode of failure of each of the different section sizes was similar. Elaboration on these differences is out of the scope of this paper.

8. Conclusions

Based on the obtained results and observations aforementioned, the following conclusions can be drawn:

1. The inclusion of fibers in a concrete matrix has been found to increase the ultimate strength, arrest the crack propagation.
2. Steel fibers are effective in providing extra shear strength to RPC reinforced concrete beams.
3. Large openings often interrupt the load transfer by concrete struts in these beams and cause a sharp decrease in strength and serviceability.
4. In this study, the ultimate strength of reinforced concrete deep beams appears to be proportioned significantly by; the procedure of loading insignificantly by; percentage of steel fiber content and size of opening.
5. The results indicate that when the steel fibers content increases the ultimate and the cracking loads are increased too.
6. Test results indicate that the fibers have significant influence on the shear strength of deep beams.
7. In particular, it is shown that the presence of steel fiber, along with the RPC, play a crucial role in the transition from flexural to shear dominated failure modes of the beam.
8. The presence of opening in the deep beams decay the ultimate load of the RPC specimens with volume fraction 1% under repeated load by 2.27 times.
9. Generally, no large differences in ultimate load values have been observed between the monotonic and repeated load for different type of solid deep beam reinforced concrete.
10. Increase of opening size decrease the ultimate load of the specimen RT-R-80-1%, RT-R-80-2% by (23.3 % , 22.8 %) as compared with the specimens (RT-R-40-1% , RT-R-40-2%) respectively.

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