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Structural Behavior of Non-Prismatic Reactive Powder Concrete (RPC) Continuous Members Under Effect of Static and Repeated Loads

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Abstract— This paper presents an experimental investigation for behavior of prismatic and non-prismatic continuous beams under effects of static and repeated loads. The experimental program contains casting and testing fourteen specimens with different parameters. The studied parameters included the effects of loading type (static and repeated load), concrete type (Reactive Powder Concrete and Normal Concrete), tapering ratio effect and presence of small circular openings with diameter 75 mm. All the specimens have the same total length of 2440 mm with two spans, each span has clear distance equal to 1150 mm. The specimens were tested under effect of concentrated load in the mid of each span. The specimens were divided into four groups. The first group contains eight specimens to study the effect of loading type, four of them tested under effect of static load and the others under repeated loads with two cases (case1: contains two specimens tested under effect of applying fifteen cycles from (0-0.75) of ultimate static load (Pu), case 2: also contains two specimens tested under effect of five cycles from (0-0.25) of Pu followed by five cycles from (0-0.5) of Pu and five cycles from (0-0.75) of Pu than finally, the beam was loaded to its ultimate load). The second group included four specimens to study the effect of concrete type on shear and flexural behavior of tested beams. The influence of tapering ratio was studied with three specimens formed group three. The final group which examine the effect of small openings included four specimens. The ultimate load, cracking load, load versus deflection curves and crack patterns were presented and discussed in this study.

Index Terms— Reactive Powder Concrete, Non-prismatic members, Continuous Members, Repeated Loads.

1 Introduction

Continuous beam is a structural component that provides resistance to bending when a load or force is applied. These beams are commonly used in bridges as shown in fig.(1). A beam of this type has more than two points of support along its length. These are usually in the same horizontal plane, and the spans between the supports are in one straight line.**[1]**

With the beams being tapered, the architects would be able to create and implement aesthetic architectural designations, as well as the structural engineers who could seek for optimum low weight - high strength systems through a redistribution of materials along the structural members.Non-prismatic members are commonly used in many engineering structures, such as highway bridges, buildings, space and air-craft structures, as well as in many mechanical components and machines. **[2]**

Fig. 1 : Non-prismatic Continuous Beam (Tongzihe Bridge in China)

The ability to construct smaller cross-section members as compared with members constructed from conventional concrete, reactive powder concrete (RPC) is one of the latest and most important development in concrete technology, it has superior mechanical properties such as; high strength, high ductility, high durability, limited shrinkage, high resistance to corrosion and abrasion and improvement in tensile cracking resistance, post cracking strength, ductility and energy absorption capacity. RPC is a mixture of cement, silica fume, fine sand, high range water reducer, water and steel fibers without coarse aggregate to enhance the homogeneity. Owing the fineness of silica fume and the increased quantity of hydraulically active components, it has been called reactive powder concrete. **[3], [4], [5].**

2 Literature Review

A brief of some research related to this study, are presented, as:

In 2006, Mingbo et al [6] studied flexural performance of 200MPa RPC with several usual contents of steel fibers based on the load-deflection curves. Prisms specimens with dimensions 100×100×400mm were tested under flexural loading. The working mechanics of the steel fibers in the bent beam was analyzed and compared with other conventional concrete. The results indicated that RPC200 had predominant flexural performance. Compared with conventional high-strength concrete and steel fibers reinforced concrete, it was found that RPC200 had a higher strength and more toughness after cracking.

Hannawayy (2010) [7]: studied the mechanical properties of RPC as well as the flexural behavior of RPC beams. The experimental program included investigation the effect of steel fiber volumetric ratio (Vf) and silica fume content (Sf) on some important mechanical properties of RPC. Also, he studied the effect of (Vf), (Sf) and longitudinal steel bar ratio (ρ) on flexural behavior of simply supported singly reinforced RPC beam. It was found from the experimental tests that increasing Vf by 2% and Sf from 5% to 15% increased each of the compressive strength by 38% and 16% respectively, splitting tensile strength by 162% and 14% respectively and modulus of rupture by 280% and 8% respectively.

Experimental investigation of the strength and behavior of reinforced concrete spandrel beams under repeated loads. Eight beams tested to failure by **Anis and Adi (2010)[8]**. In this study, two types of cross sections for spandrel beams were considered, the first was a solid rectangular section, while the other was a hollow rectangular section. Also, the load was repeated at two stages, the first was a soft-cracking stage. At this stage, the load was repeated using seven cycles. The second stage, at which the load was repeated, was after yielding of the bottom longitudinal reinforcement at the mid span.

Shear behavior of reactive powder concrete T-beams investigation was done by **Al-shafi'i (2013)[9]**. Fifteen simply supports RPC T-beams and an additional RPC rectangular beam (acting as a reference beam) were cast and tested up to failure under two point loading. The beams had no stirrups and were heavily reinforced longitudinally to ensure shear failure to occur in all beams. It was found that the increase of steel fibers (Vf) from 1% to 2% increased the diagonal cracking load (Pcr) from 20% to 60% and increasing ultimate shear load (Pu) from 55.8 % to 171.2% respectively as compared to non-fibrous RPC T-beams. However, the increase in the other variable such as ρw and SF had lesser effects on the cracking at ultimate loads. Increasing a/d ratio from 2.5 to 3.5 and 4.3 with Vf = 2% and ρw = 7.7% decreased both Pcr by 11.11% and 33.33% respectively and Pu by 41.4% and 52.3% respectively.

Adheem (2016)[10], studied the behavior and performance of composite concrete members which is consisting of precast-presstressed concrete beams with reactive powder concrete (RPC) slabs under effect of repeated loads. Also, the present study aimed to know of the impact and effectiveness of using the reactive powder concrete (RPC) instead of conventional concrete in the slab of composite concrete member. It was found experimentally that the structural behavior of composite concrete members was significantly affected by increasing the level of repeated load. However, as this level increased from 0.33Pu (corresponding to first cracking load) to 0.5Pu, and from 0.33Pu to 0.7Pu the ultimate flexural strength decreased by 4.82% and 11.25%, then maximum deflection (Δu) increased by 22.2% and 44.4% respectively. Moreover the ultimate shear strength Vu decreased by 9.5% and maximum deflection (Δu) increased by 28.6% when the level of repeated load increased from 0.33Vu to 0.7Vu.

3 Materials

Normal concrete strength contain the main compound of mixture which is cement, fine aggregate, coarse aggregate and water. RPC is a mixture of cement, silica fume, fine sand, high range water reducer, water and steel fiber without coarse aggregate. The materials were according to Iraqi specifications.

4 Mix Proportion

All the mix proportion was selected according to the previous researches and shown in Table 1.

Table 1. Details of Mixes for the Present Study

Mix Type	Cement (Kg/m³)	Micro Silica Fume (Kg/m³)	Sand (Kg/m³)	Steel Fiber by Volume (%)	Gravel (Kg/m³)	Water Cementetious ratio	Super Plasticizer by Weight of Cementetious
RPC	850	150	1000	2	--	0.17	3.5%
NC	400	--	600	--	1000	0.4	--

5 Details of Tested Speciemens

In this study fourteen specimens with different geometry were tested and they are:

1. Five prismatic specimens.
2. Five non-prismatic specimens with tapering ratio equal to (1.33).
3. Two non-prismatic specimens with tapering ratio equal to (1.594 and 1.875).
4. One of both prismatic and non-prismatic samples with opening.

Table 2. shows the details of tested specimens.

Table 2. Details of Specimens

Group	Symbol	Failure Mode	Type of Concrete	Type of Beam	Type of Load	Presence of Opening	Tapering Ratio(H_2/H_1)
Group 1 (Static and Repeated Load Effect)	B3	Flexure	RPC	Prismatic	Static	Without	1
	B5	Flexure	RPC	Prismatic	Repeated (0-0.75) Pu	Without	1
	B4	Flexure	RPC	Non-Prismatic	Static	Without	1.33
	B6	Flexure	RPC	Non-Prismatic	Repeated (0-0.75) Pu	Without	1.33
	B1	Flexure	RPC	Prismatic	Static	Without	1
	B7	Flexure	RPC	Prismatic	Repeated (increments)	Without	1
	B2	Flexure	RPC	Non-Prismatic	Static	Without	1.33
	B8	Flexure	RPC	Non-Prismatic	Repeated (increments)	Without	1.33
Group 2 (Type of Concrete Effect)	B4	Flexure	RPC	Non-Prismatic	Static	Without	1.33
	B9	Shear	NC	Non-Prismatic	Static	Without	1.33
	B2	Flexure	RPC	Non-Prismatic	Static	Without	1.33
	B10	Flexure	NC	Non-Prismatic	Static	Without	1.33
Group 3 (Tapering Ratio Effect)	B4	Flexure	RPC	Non Prismatic	Static	Without	1.33
	B11	Flexure	RPC	Non-Prismatic	Static	Without	1.594
	B12	Flexure	RPC	Non-Prismatic	Static	Without	1.875
Group 4 (Effect of Opening)	B3	Flexure	RPC	Prismatic	Static	Without	1
	B13	Shear	RPC	Prismatic	Static	With	1
	B4	Flexure	RPC	Non-Prismatic	Static	Without	1.33
	B14	Flexure	RPC	Non-Prismatic	Static	With	1.33

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6 Reinforcement Details

The properties and details of reinforcement for the tested specimens are shown in Table (3) and Fig. (2).

Table 3. Steel Bar Properties

Nominal Diameter (mm)	Yield Strain	Yield Stress (Mpa)	Ultimate Strength (Mpa)	Modulus of Elasticity (Mpa)
6	0.0024	480	550	200000
10	0.0025	580	650	200000

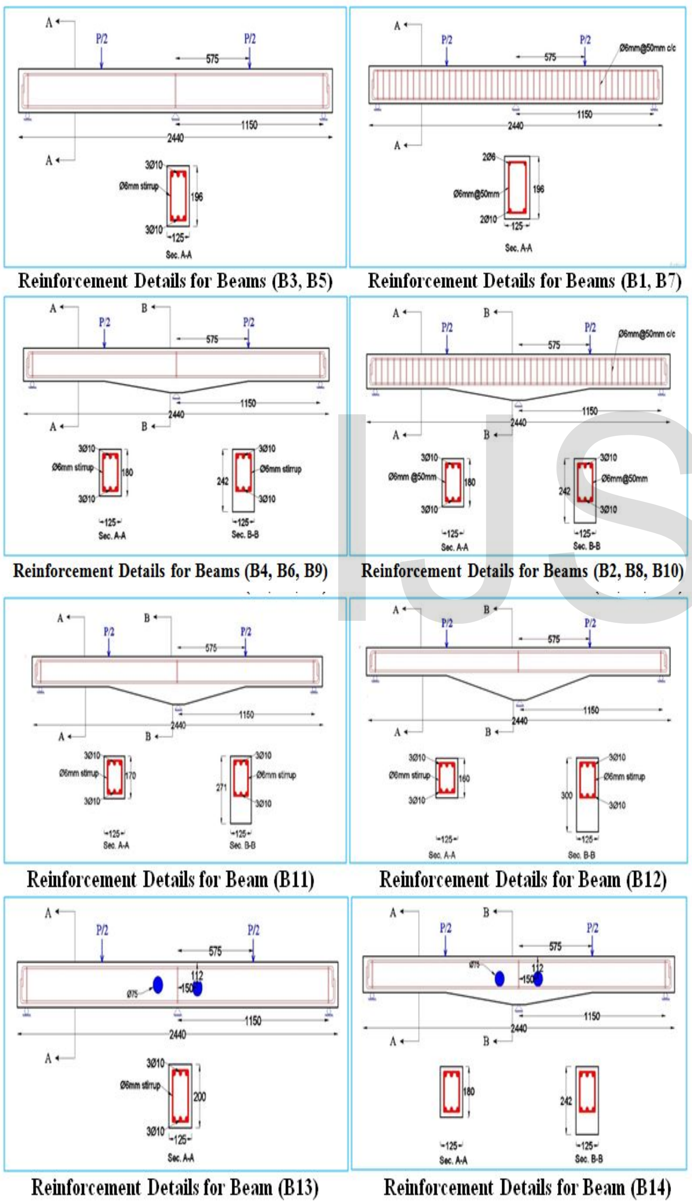

Fig. 2: Show the Reinforcement Details and Geometry for Tested Specimens

7 Experimental Results and Discussions

7.1 Repeated Loads Effect

The experimental results showed that beams subjected to repeated load (with 15 cycles and incremental increasing case) always caused some increase in the deflection in consecutive cycles, the consecutive increase of deflection with repeated loads was found to decrease [at the same applied of load level]. Figures (3 -10) show the load versus deflection curves for the group one tested specimens. Also, the results explained that repeated load has insignificant effect on the ultimate load capacity and failure mode of the tested beams that was returned to the ability of steel fiber to enhance the energy dissipation capacity of tested beams under repeated load. The summary of results for the tested beams are shown in Table 4. and Figures (11-18) showed the crack pattern and failure mode.

Table 4. Experimental Results for Group One Tested Beams

Group No.	Beam Name	Applied Load (KN)			Ultimate Mid Span Deflection (mm)
		Pu*	Pcr*	Pcr/Pu	
1	B1	239	61	0.255	8.85
	B7	237	75	0.316	11.5
	B2	248	64	0.258	13
	B8	248	50	0.201	15
	B3	393	81	0.206	12.07
	B5	392	59	0.15	15.6
	B4	410	63	0.153	17.056
	B6	409	40	0.098	22.7

*Pu : Ultimate Load Capacity.
*Pcr : Cracking Load.

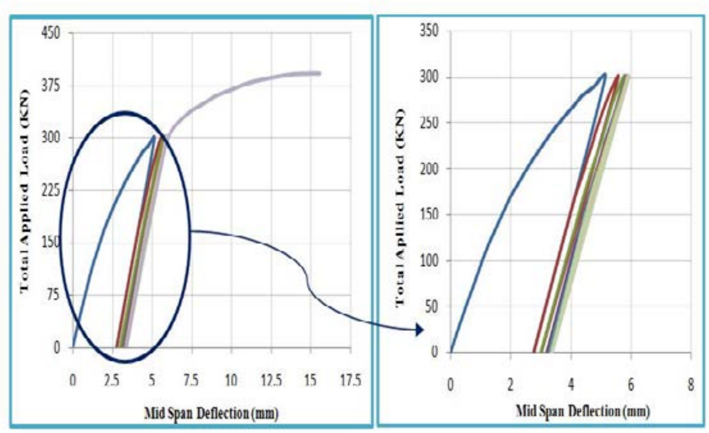

Fig. (3): Load-Deflection Curves for B5

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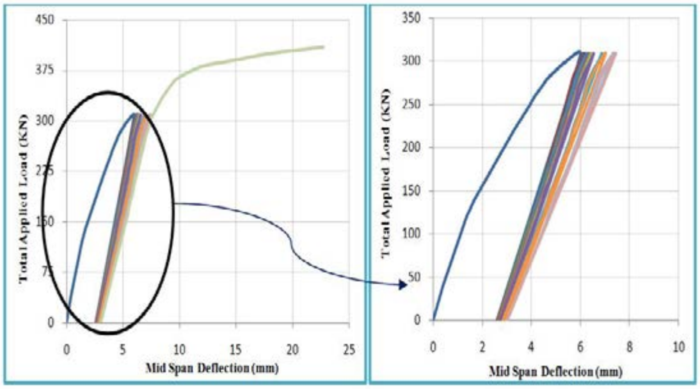

Fig. (4) : Load-Deflection Curves for B6

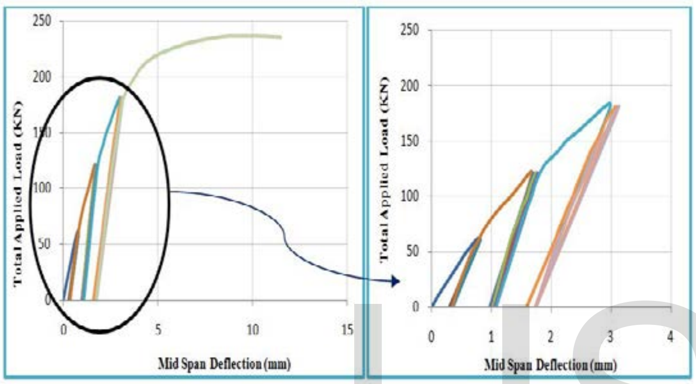

Figure (5) : Load-Deflection Curves for B7

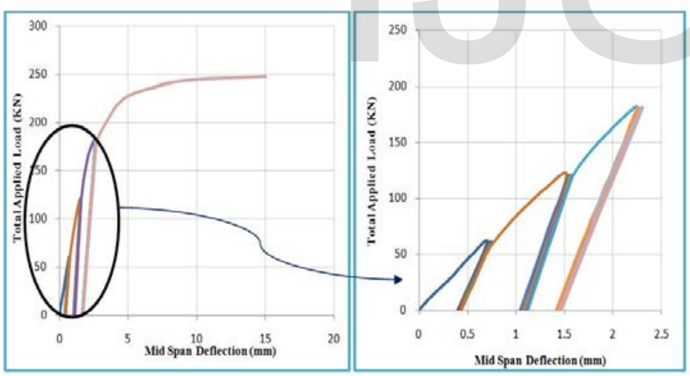

Figure (6) : Load-Deflection Curves for B8

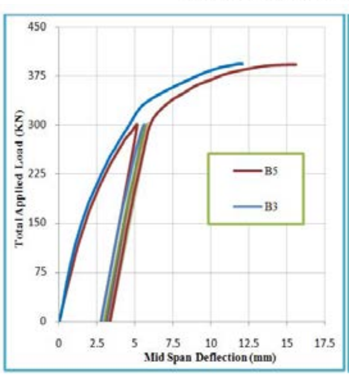

Fig. (7): Load-Deflection Curves for B3 and B5

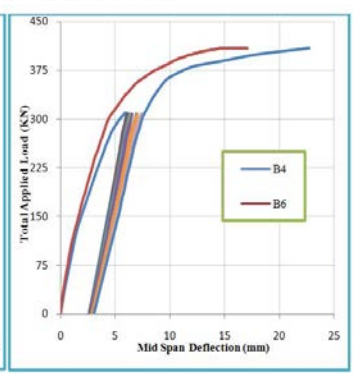

Fig.(8) :Load-Deflection Curves for B4 and B6

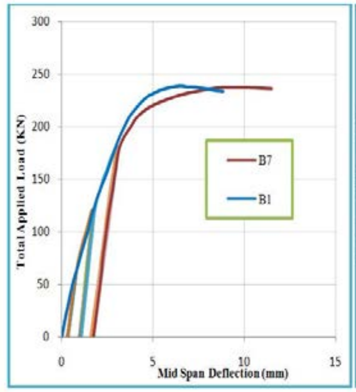

Fig.(9) :Load-Deflection Curves for B1 and B7

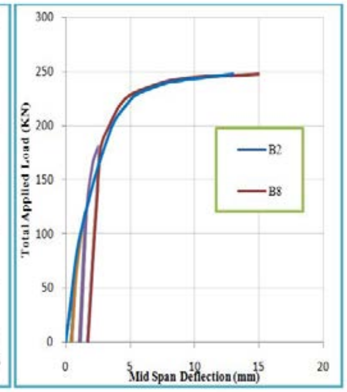

Fig.(10) :Load-Deflection Curves for B2 and B8

Fig. (11):Crack Pattern for B1

Fig. (12): Crack Pattern for B2

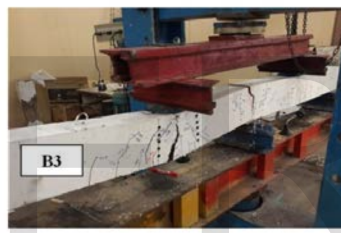

Fig. (13): Crack Pattern for B3

Fig. (14): Crack Pattern for B4

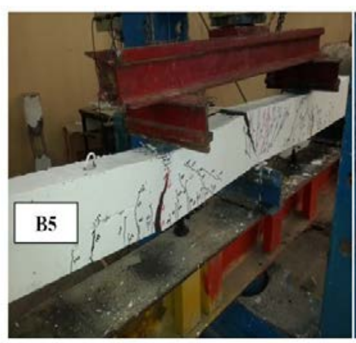

Fig. (15): Crack Pattern for B5

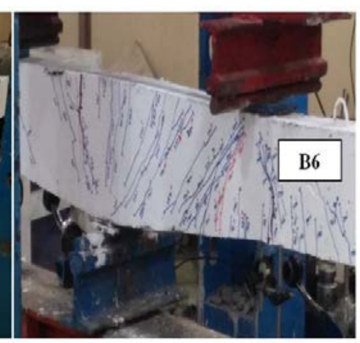

Fig. (16): Crack Pattern for B6

Fig. (17): Crack Pattern for B7

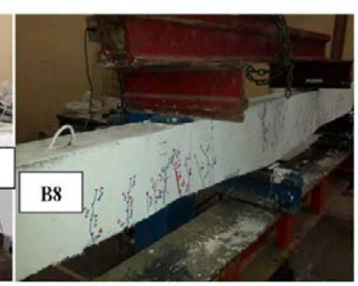

Fig. (18)Crack Pattern for B8

7.2 Effect of Concrete Type

The experimental results showed that the beam B2 enhance and give an increase in the flexural ultimate capacity at about (51.22)% with an increase in number of cracks (more warning before failure) as compared with beam B10. The results showed that the beam B4 developed the ultimate shear capacity at about (177.11)% (despite the beam has not reached ultimate shear capacity) as compared with result of B9 beam. Also, The RPC beams had a ductile behavior more than NC beams with percentage increment equal to (34.1)% and give an increase in total number of cracks (more warning before failure) at about (62.16)% The summary of results for the tested beams are shown in Table 5. Figures (19-22) showed the load deflection curves and crack pattern for tested specimens.

Table 5: Experimental Results for Group Two Tested Beams

Group No.	Beam Name	Applied Load (KN)			Ultimate Mid Span Deflection (mm)
		Pu	Pcr	Pcr/Pu	
2	B10	164	40	0.244	8
	B2	248	64	0.258	13
	B9	116	30	0.258	2.325
	B4	410	63	0.153	17.056

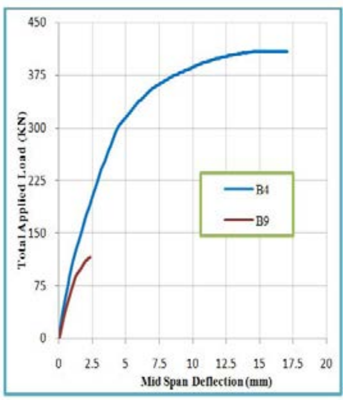

Fig. (19):Load-Deflection Curves for B4 and B9

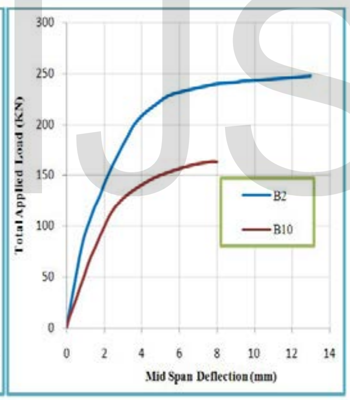

Fig. (20):Load-Deflection Curves for B2 and B10

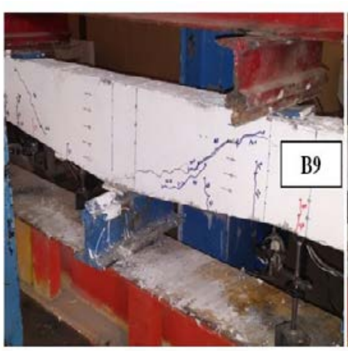

Fig. (21): Crack Pattern for B9

Fig. (22): Crack Pattern for B10

7.3 Effect of Tapering Ratio

The experimental results showed that increasing in tapering ratio lead to an increase in ultimate load capacity at about (7.56)% for B11 and (14.39)% for B12 as compared with ultimate capacity of B4 beam because of the development in rotation capacity of plastic hinge due to increasing in depth at critical section (negative moment) allow the member to redistribute more percent of the moment to other section until a collapse mechanism forms. Also, the results showed that increasing in tapering ratio from (1.33) to (1.594 and 1.875) lead to an increase in ductility at about (23.55)% and (5.34)% respectively as compared with the control beam B4. The summary of results for the tested beams are shown in Table 6. Figures (23-25) showed the load deflection curves and crack pattern for tested specimens.

Table 6. Experimental Results for Group Three Tested Beams

Group No.	Beam Name	Applied Load (KN)			Ultimate Mid Span Deflection (mm)
		Pu	Pcr	Pcr/Pu	
3	B4	410	63	0.1536	17.056
	B11	441	50	0.1134	19.88
	B12	469	87	0.1855	23.04

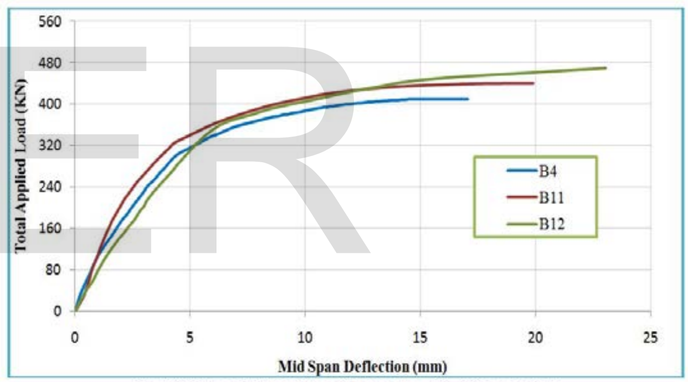

Fig. (23):Load-Deflection Curves For B4, B11 and B12

Fig. (24): Crack Pattern for B11

Fig. (25): Crack Pattern for B12

7.4 Effect of Small Circular Openings

The experimental results showed that presence of opening near interior support in prismatic member (B13) decreased the ultimate load capacity at about (18.57) % as compared with control beam (B3) and changed the mode of failure from flexural mode to beam type failure mode (shear failure). In other hand, the presence of opening in non-prismatic member (B14) had insignificant effect on ultimate capacity and mode of failure. The summary of results for the tested beams are shown in

Table 7. Figures (26-28) showed the load deflection curves and crack pattern for tested specimens.

Table 7. Experimental Results for Group Five Tested Beams

Group No.	Beam Name	Applied Load (KN)			Ultimate Mid Span
		Pu	Pcr	Pcr/Pu	Deflection (mm)
4	B3	393	81	0.206	12.07
	B13	320	65	0.203	8
	B4	410	63	0.153	17.056
	B14	409	78	0.1907	16

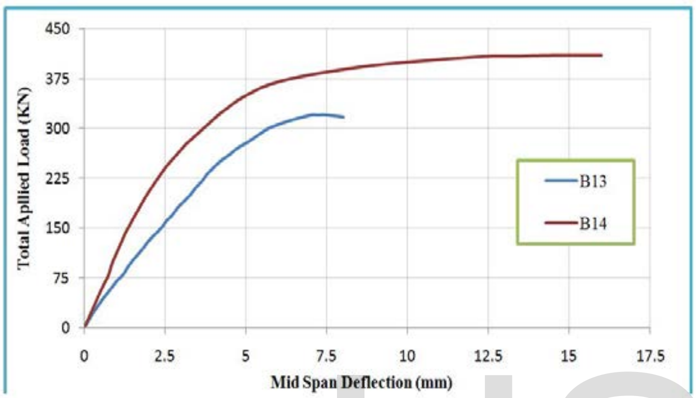

Fig. (26):Load-Deflection Curves for B13 and B14

Fig. (27): Crack Pattern for B13 Fig. (28): Crack Pattern for B14

8 Conclusions

1. It is clear from the results that repeated load in both cases [case of applying (15) cycles to (0.75) of ultimate load and case of incremental increases] has insignificant effect on flexural ultimate capacity of RPC continuous beams, while show an increase in deflection at about (15.38-29.94)% for incremental increases case and (29.24-33.09)% for other case as compared with control beam tested under static load.
2. Experimental results explained that using RPC instead of NC in continuous beam enhanced the flexural ultimate capacity at about (51.22)% and recorded an increase in ultimate shear capacity more than (177.11)%, while the deflection decreases (65.93)% and (44.08)% for flexural and shear member respectively at the ultimate load of NC beams.
3. The RPC beams had a ductile behavior more than NC beams with percentage increment equal to (34.1)% and give an increase in total number of cracks (more warning before failure) at about (62.16)% .
4. Increasing tapering ratio from (1.33) to (1.594 and 1.875) with same amount of concrete enhanced from ultimate flexural capacity at about (7.56)% and (14.39)% and decreased the mid span deflection by (40.47)% and (34.35)% respectively at the ultimate load of control beam.
5. Results showed that increasing in tapering ratio lead to a ductile behavior before failure, the increasing in ductility ratio was (23.55)% and (5.34)% when the tapering ratio increased from (1.33) to (1.594 and 1.875) respectively.
6. Presence of small circular openings near interior support and at specified depth in the prismatic continuous beam reduced the ultimate load capacity at about (18.75)% and changed the mode of failure from flexural mode to shear failure mode.
7. Presence of small circular opening near interior support and at specified depth in the non prismatic member with tapering ratio (1.33) had insignificant effect on structural behavior of beam.

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