

Punching Shear Behavior of Continuous Bubbled Reinforced Reactive Powder Concrete Slab

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Abstract:

This paper presents an experimental investigation on punching shear behavior of continuous bubbled reinforced Reactive Powder Concrete (RPC) slabs. Bubbled slab is one of the various types of voided slabs. It consists of bubbles placed inside a concrete slab which will reduce the self-weight of the structure by about 35% (Tina Lai 2009). On the other hand, using RPC make it possible for structural member to have smaller dimensions due to the great strength of this type of concrete. In this study, these two method to increase the building spaces dimensions by reducing self-weight of the structure by using bubbled slabs and to decrease the structural members' dimensions by using RPC have been investigated together.

To study the punching shear behavior of continuous bubbled flat slabs such as the ultimate load carrying capacity, central deflection and slabs crack pattern at the ultimate load, nine different types of slabs were tested. The parameters of the study were type of concrete (RPC and Normal Concrete (NC)), bubbles diameter to slab thickness ratio (D/t) of (0.6 and 0.7), bubbles location (at all slab area, started from distance D and $1.5D$ from the center slab) and solid slab.

The test results show that the crack pattern and ultimate load capacity as well as maximum deflection depends on all of the mentioned parameters, were by increasing (D/t) ratio the ultimate load capacity increases about (6.49 and 9.58%) for slabs with bubbles started at distance $2D$ and $3D$, respectively. But in the slabs with bubbles at all slab area the ultimate load and the maximum deflection decreases about (6.63 and 9.47%) and (7.96 and 6.84%) for RPC and NC slabs, respectively. Also, the solid slab increases the ultimate load about (5.28%) compare to bubbled slab at all area.

It was found that by removing bubbles from center of the slab at distance $2D$ and $3D$ the ultimate load will increase about (14.72 and 8.76%), respectively for slabs with ($D/t = 0.6$) compare to slabs with bubbles at all slab area, and for slabs with ($D/t = 0.7$) the ultimate load will increase about (30.85 and 27.65%), for bubbles at distance $2D$ and $3D$, respectively.

Using the NC decreases the ultimate load compare to RPC by about (52.82-54.25%) for different (D/t) ratio.

Keywords: Bubble-Deck slab, Punching shear behavior of continuous slab, Plastic sphere, Reactive Powder Concrete slab.

الخلاصة:

يهتم هذا البحث بدراسة تحمل القص للبلاطات الخرسانية المستمرة الفقاعية ذات المساحيق الفعالة. البلاطات الفقاعية هي أحد أنواع البلاطات المجوفة والتي تتكون من كرات بلاستيكية توضع بداخل الخرسانة والتي تقلل من الوزن الذاتي للبناء بمقدار 35%. من طرف آخر، استخدام خرسانة ذات المساحيق الفعالة تقلل ابعاد الاعضاء الانشائية نتيجة لمقاومتها العالية. في هذا البحث تم التحري على هذين العاملين وهما زيادة ابعاد الفضاءات الداخلية بتقليل الوزن الذاتي باستخدام البلاطات المجوفة وتقليل ابعاد الاعضاء الانشائية باستخدام خرسانة ذات المساحيق الفعالة.

لدراسة سلوك القصية للبلاطات المستمرة والمجوفة والمتمثل ب (الحمل الاقصى، الانحراف المركزي وشكل التشققات)، تم اختبار تسعة انواع من البلاطات. المتغيرات في هذه الدراسة تشمل نوع الخرسانة (خرسانة الاعتيادية والخرسانة ذات المساحيق الفعالة)، نسبة قطر الكرة إلى سمك البلاطة بقيمة (0.6 و 0.7)، موقع الكرات البلاستيكية (في كل مساحة البلاطة، تبدأ بمسافة $2D$ و $3D$ عن مركز البلاطة)، واستخدام نموذج صلد (الغير المجوفة).

نتائج الاختبار أظهرت أن شكل التشققات والتحمل الاقصى وكذلك الانحراف المركزي يعتمد على جميع العوامل المذكورة اعلاه، حيث بزيادة نسبة قطر الكرة الى سمك البلاطة تم ازدياد التحمل الاقصى بحدود (6.49% و 9.58%) لبلاطات ذات الكرات البائدة من مسافة $2D$ و $3D$ ، على التوالي. لكن في البلاطات ذات الكرات في كل مساحة البلاطة التحمل الاقصى والانحراف الاعلى تقل بحدود (6.63 و 9.47%) و (7.96 و 6.84%) للبلاطات الحاوية على خرسانة ذات المساحيق الفعالة والخرسانة الاعتيادية، على التوالي. كذلك، البلاطة الصلدة تزيد التحمل الاقصى بحدود (5.28%) مقارنة مع البلاطة المجوفة في كل مساحة البلاطة.

وجد بأن إزالة الكرات من مركز البلاطة بمسافة $2D$ و $3D$ التحمل الاقصى تزيد بحدود (14.72 و 8.76%)، على التوالي

للبلطات ذات نسبة قطر الكرة الى سمك البلاطة بقيمة (0.6) مقارنة مع البلطات ذات كرات في كل مساحة البلاطة، وللبلطات ذات نسبة قطر الكرة الى سمك البلاطة بقيمة (0.7)، التحمل الاقصى تزيد بحدود (30.85 و 27.65%)، للبلطات ذات الكرات بمسافة 2D و 3D، على التوالي.

استخدام الخرسانة الاعتيادية تقلل من التحمل الاقصى مقارنة مع الخرسانة ذات المساحيق الفعالة بحدود (52.82- 54.25%) لنسب المختلفة من قطر الكرة الى سمك البلاطة.

الكلمات المفتاحية: البلطات المجوفة، تحمل القص لبلاطة مستمرة، الكرات البلاستيكية، البلاطة ذات المساحيق الفعالة.

1) Introduction

Reinforced concrete slabs are widely used in building constructions as floor systems. The flat slab is an important type of reinforced concrete floor system since it is one of the largest member consuming concrete (Amer et. al. 2013).

Generally the slabs were designed to resist vertical loads (dead loads and live loads) only, but in residential environment the noises and vibration of upper floor become more important recently (J.H.Chung et. al. 2009).

In addition to achieve some of the architectural or structural requirements like large spans the slab thickness should be increased to avoid large deflections. By increasing the thickness of the slab it will be heavier and needs larger columns and foundations to resist the additional loads. Thus, the buildings will consuming more material such as concrete and steel reinforcement that will cause more cost and reduced the possible spaces (J.H.Chung et. al. 2009). So, to avoid these kind of disadvantages that are caused by increase in slab self-weight some solutions were suggested:

- 1) Usage of bubble-deck slab system.
- 2) Usage of Reactive Powder Concrete (RPC).

2) Bubble-Deck Slab System

The bubble-deck slab system is the patented integration technique of linking air, steel, and concrete in a slab by locking hollow recycled plastic spheres that inserted into the slab between the top and bottom reinforcement meshes, thereby creating a natural cell structure, acting like a solid slab (A.Churakov 2014) but with considerably less weight due to the elimination of superfluous concrete.

This system of slabs has some advantages like:

- Flexibility in design which can easily adapts to irregular and curved plan layouts, longer spans and fewer supports (Nasvik J. 2011).
- Down stand beams and bearing walls eliminated: Quicker and cheaper erection of walls and services (Harding P. 2004).
- Reducing overall costs: The material consumption will reduced and construction will be faster (Nasvik J. 2011).
- Reduced dead weight by about 35% which allows smaller foundation sizes.
- Longer spans between columns: Up to 50% further than traditional structures.
- Reduced foundation sizes: There is up to 50% less structural dead-weight.
- Reduced concrete usage: 1 kg of recycled plastic replaces 100 kg of concrete.
- Environmentally Green and Sustainable: Reduced energy & carbon emissions. 8% of global CO₂ emissions are due to cement production (A. Churakov 2014).
- Use of recycled materials.
- Easy installation of mechanical, electrical and plumbing (MEP) lines and fixtures within the floor.

3) Reactive Powder Concrete

Reactive Powder Concrete (RPC) is the generic name for a class of cementitious composite materials. It is characterized by extremely good physical properties,

particularly strength and ductility. Even though RPC is considerably more expensive to produce than regular concrete, its more isotropic nature and greater ductility make it competitive with steel, over which it has a significant cost advantage, for many structural applications (N.P.Lee 2005).

The RPC provides many advantages compared to conventional concrete as listed in the following:

- Superior strengths approximately four times the strengths of conventional concrete result in significant savings in dead load. Weight reduction is good in producing more slender transportation structures, reducing overall costs and increasing usable floor space in high-rise buildings (Rebentrost, M. Cavill 2006).
- Superior durability which leads to long service life with reduced maintenance.
- Elimination of steel reinforcement bars reduces high labour costs and provides greater architectural freedom. That means it allows nearly limitless structural member shapes and forms for the architects and designers (Dauriac 1997).
- A significant amount of unhydrated cement in the finished product provides a self-healing potential under cracking conditions (Dauriac 1997).

4) Experimental Program

4.1 Materials

- Cement

Sulfate resistance Portland cement (type V) manufactured by Karbala cement factory, Iraq, was used in casting all the specimens throughout this study. Its physical and chemical composition and properties are conformed to the Iraqi Specifications limits (I.Q.S. 5/1984) for sulfate resistance Portland cement.

- Fine Aggregate

Natural sand was used as fine aggregate in both RPC and normal concrete. For NC the sand was sieved to achieve maximum particle size of (4.75mm) and for RPC it was sieved to achieve finer particles with maximum size of (600 μ m). Its gradation lies within zone (3) and its sulfate content conformed by Iraqi specification (I.Q.S 45/1984).

- Admixtures

Two types of concrete admixtures were used in the present study:

• Super Plasticizer (SP)

To produce the RPC mixture in the present study GLENIUM® 54 was used as Super Plasticizer (SP) which based on modified polycarboxylic ether. It has been primarily developed for applications in the ready mixed and precast concrete industries where the highest durability and performance is required.

• Silica Fume

In this study sika® fume S92D which based on densified silica fume has been used as a mineral admixture added to the RPC mixture. The dosage used was 10% as partial replacement of cement weight. The chemical composition and physical properties of the silica fume conformed to (ASTM C311-96) specifications.

- Polymer Fibers

Single fibers (monofilaments) with a wavy shape polymer fibers were used to increase the ductility of the RPC throughout this study with dosage of 2.4 Kg per m³ concrete mix. It has diameter of 0.78mm, length 39mm, specific surface 2350 cm²/g and ultimate tensile strength of 470 MPa.

- Recycled Plastic Balls

In the present study to make bubbles inside the slabs, plastic balls manufactured from recycled plastic with different diameters of (60 mm and 77 mm) are used. The purpose of using recycle material is to conserve energy because it takes

far less energy to reprocess recycled materials into new materials than to process virgin materials. Also, recycling helps reduce global warming and reduce air pollution by reducing the amount of industrial work that must be completed to create a new product. In other hand, products that are recycled will not go to landfills and will, in turn, not contribute to the amount of waste materials there are on Earth and there is more room in the landfills for non-biodegradable garbage materials. So, by recycling, people can greatly contribute to the earth's overall health and keep the air, water and land clean.

- Steel Reinforcing Bars

For all slabs, deformed steel bars are used as the steel reinforcement at top and bottom of the slabs. All steel bars, in long and short direction have the same size of (ϕ 6 mm) in diameter. The mechanical properties of tested steel bar are given in Table (1).

Table (1): Tested Steel Bars Mechanical Properties.

Bar size (mm)	area (mm ²)	weight (kg/m)	density (kg/m ³)	E (GPa)	Yield strength F_y (MPa)	Yield strain	Ultimate strength F_u (MPa)
ϕ 6	28.3	0.222	7844.5	200	480	0.0024	550

- Coarse Aggregate (Gravel)

Crushed stone was used as coarse aggregate (gravel) in normal concrete mixture in this study with a maximum grade size of (19 mm). The gradation and other physical properties of coarse aggregate conformed to the limits specified by Iraqi Specification (I.Q.S. 45/1984).

4.2 Specimens Description

The tested continuous bubbled slabs were contained of nine different types of slabs. The test parameter included the bubbles diameter to slab thickness (D/t) ratio (0.6 and 0.7), type of the concrete (RPC and NC), bubbles location (at all slab area, started at distance 2D and 3D from the center slab) and solid slab. The test specimens identification and dimensions are illustrated in Table (2) and Figure (1).

Table (2): Specimens Identification.

Slab No.	Slab Symbol	Concrete Type	Slab Thickness t (mm)	Bubbles Diameter D (mm)	(D/t)	Position of Bubbles
S8	PA10	RPC	100	60	0.6	at all slab area
S9	PA11	RPC	110	77	0.7	at all slab area
S10	PS	RPC	100	-	solid	-
S11	P2D10	RPC	100	60	0.6	started at 2D
S12	P2D11	RPC	110	77	0.7	started at 2D
S13	P3D10	RPC	100	60	0.6	started at 3 D
S14	P3D11	RPC	110	77	0.7	started at 3 D
S15	PN10	N	100	60	0.6	at all slab area
S16	PN11	N	110	77	0.7	at all slab area

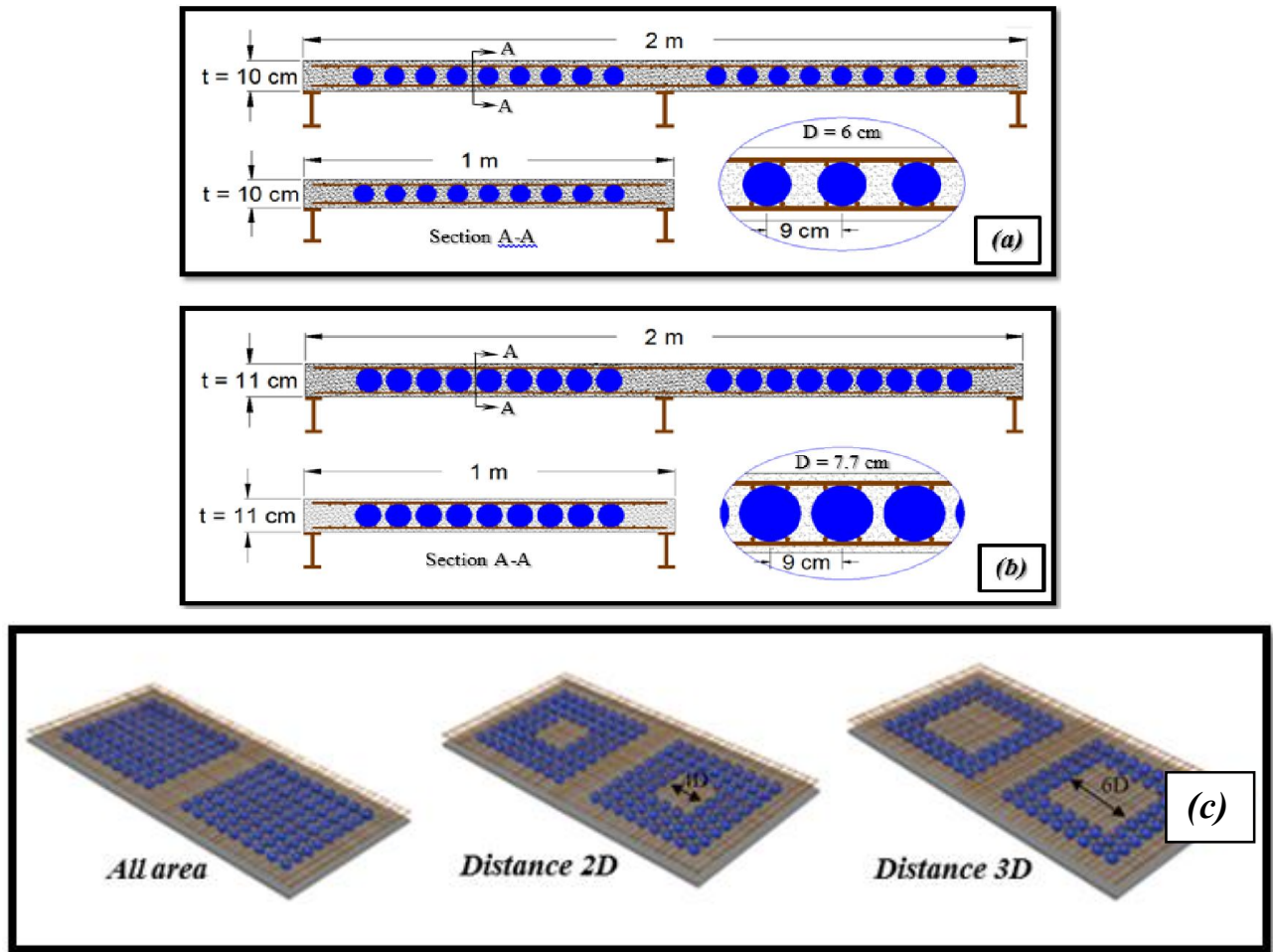


Figure (1): Schematic Representation of Slabs.

- (a) Slabs dimensions and bubbles spacing for (0.6) (D/t) ratio.
- (b) Slabs dimensions and bubbles spacing for (0.7) (D/t) ratio.
- (c) Bubbles location at all area, from distance 2D and from distance 3D.

4.3 Concrete Mixes

This study contains two types of concrete (RPC and NC). To produce RPC the designer must consider some main steps and some optional steps. By applying these steps the produced RPC will have desirable properties.

- The main steps are:

- 1) Omitting coarse aggregate that will enhance concrete's homogeneity.
- 2) Optimize granular mixture that will enhance concrete's density.
- 3) Using of pozzolanic materials (silica fume) that will enhance concrete's density and reduces anhydrate cements.
- 4) Using (SP) that will reduces w/c ratio and enhances concrete's workability.
- 5) Hot curing that will improve micro structure of the concrete.

- The optional steps are:

- 1) Adding fibers that will enhance concrete's ductility.
- 2) Pressure during and after setting that will enhance concrete's density.

Within the above limits the trial mixes were designed and correction was applied to mix proportions to obtain an acceptable compressive strength. Table (3) and Table (4) shows the material content of the RPC and NC mixture.

Table (3): Reactive Powder Concrete (RPC) Mix Content.

Concrete symbol	cement (kg/m ³)	fine sand (kg/m ³)	silica fume (%)	silica fume content (kg/m ³)	polymer fiber content (kg/m ³)	w/c ratio	SP content liter/m ³
RPC	950	1100	10	95	2.4	0.16	10

Table (4): Normal Concrete Mix Content.

Concrete symbol	cement (kg/m ³)	sand (kg/m ³)	C.A* (kg/m ³)	w/c ratio
NC	280	730	1280	0.4

* Maximum size of coarse aggregate was 19 mm.

4.4 Mixing of Concrete

All RPC mixes were performed in a rotary mixer of (0.1 m³). For RPC concrete the mixing procedure was as follows:

- 1) The silica fume and cement were mixed in dry state for about 3 minutes to disperse the silica fume particles throughout the cement particles.
- 2) The sand was added and the mixture was mixed for 2 minutes.
- 3) 75% of the required quantity of the mix water was added and whole constituents were mixed for 3 minutes.
- 4) Polymer fiber was uniformly distributed into the mix and mixed for 5 minutes.
- 5) The super plasticizer (SP) was dissolved in the remaining water and the solution of water and super plasticizer was added gradually during the mixing process then the whole mixture was mixed for 8 minutes.

In total, the mixing of one batch requires approximately 16 minutes from adding water to the mix.

4.5 Preparation of Test Specimens

All of the tested slabs were made by pouring the concrete in to the molds after the mixing process was completed. The molds were cleaned and oiled to prevent adhesion to concrete after hardening. Two layers of steel reinforcement mesh was placed inside the mold at top and bottom of the spherical plastic balls. After pouring the concrete, its upper surface was smoothly finished using a hand trowel. Figure (2) illustrate the preparation of test specimens.

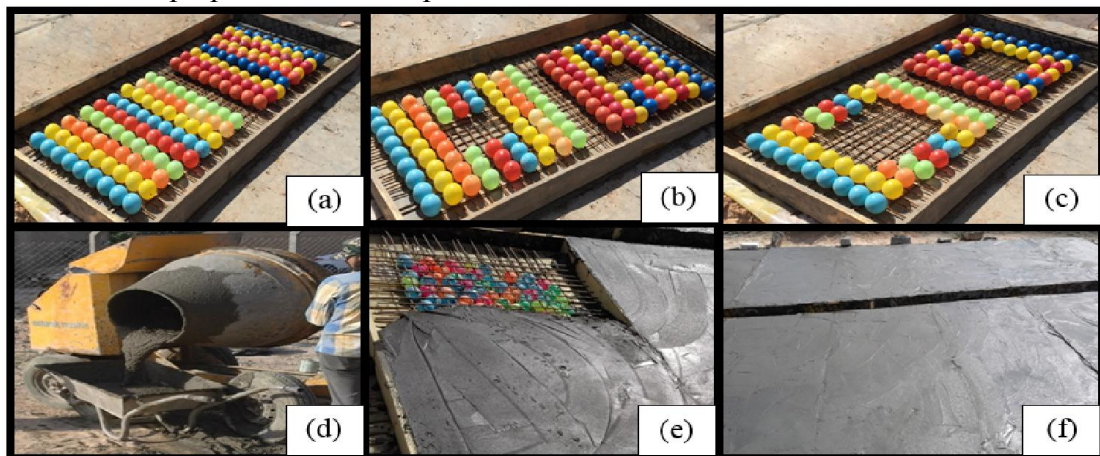


Figure (2): Preparation of test specimens steps: (a) Placing bubbles on bottom steel mesh inside the mold at all area, (b) From distance 2D, (c) From distance 3D. (d) Pouring concrete after compilation of mixing process. (e) Pouring concrete into the molds after placing top steel mesh. (f) Slabs specimens after casting and smoothing the finished surface.

- Concrete Curing

The curing process was started after 24 hours of casting by submerging all specimens in hot water at about 60°C for 48 hours. After that they were left to be cooled gradually at room temperature in water until the end of water curing at 28 days.

- Concrete Mechanical Properties

The mechanical properties of the RPC and NC were obtained by testing cubic samples of RPC and NC. Tables (5) and (6) show the mechanical properties of RPC and NC, respectively.

Table (5): Mechanical Properties of RPC.

f'_c MPa	E GPa	Density kg/m^3	ν	F_t MPa
103.7	40	2600	0.2	7.85

Table (6): Mechanical Properties of Normal Concrete.

f'_c MPa	E GPa	Density kg/m^3	ν	F_t MPa
24.2	23.12	2400	0.2	1.51

4.6 Test Procedure

- Steel support bed

A manufactured steel support bed was used to perform simply support at slab edges as well as continuous edges support. The perspective view of steel support bed is shown in Figure (3-a).

- Loading steel beam

The applied load in the Universal Testing Machine is a vertical concentrated load. Thus, to transfer this load to the continuous slab a steel beam with one concentrated point load was used, as shown in Figure (3-b).

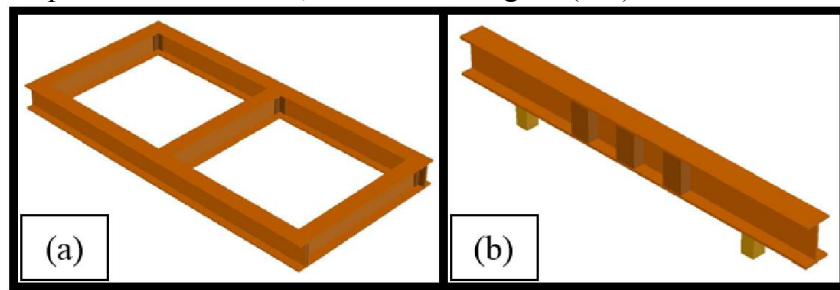


Figure (3): (a) Perspective View of Steel Support Bed.

(b) Loading steel beam with one concentrated pointed load.

- Specimens testing

All of the specimens were tested by using universal testing machine under monotonically increasing applied load up to failure. The applied load was increased gradually and displayed on the machines monitor, the central deflection was observed manually throughout the loading operation by using dial gages at the center of each continuous slab. Figure (4) shows test setup and instrumentation used for the tested slabs and Figure (5) shows dial gauge used to measuring central deflection.



Figure (4): Test Setup and Instrumentation.



Figure (5): Dial Gauge Used to Measuring Deflection.

5) Experimental Results

The results obtained from the experimental tests which are ultimate load carrying capacity and maximum central deflection were divided into four group. Each group contains study on one parameter effect. These groups are as follows:

- Effect of (D/t) ratio:

From the experimental results it was found that by increasing (D/t) ratio about (16 %) from (0.6) to (0.7) the ultimate load carrying capacity will increase about (6.49%) and (9.58%) for slabs with bubbles started at distance 2D and 3D, respectively, due to increase in cross section area. The maximum deflection of these slabs have also been increased by about (4.37%) and (8.76%), respectively. But in the slabs with bubbles at all slab area the ultimate load will decrease due to the reduction in covers distance, about (6.63%) and (9.47%) and the deflection also decrease about (7.96%) and (6.84%) for RPC slabs and NC slabs, respectively.

Table (7) shows the specimens test results and Figures (6-a-d) represent comparison of load-deflection curves between (PA10 and PA11), (P2D10 and P2D11), (P3D10 and P3D11) and (PN10 and PN11).

Table (7): Effect of (D/t) ratio on the ultimate load carrying capacity and maximum deflection.

Slab Type	Bubble Location	Slab designation	(D/t) ratio	P_u (kN)	δ_u (mm)	% increase in P_u	% increase in δ_u	% weight reduction
RPC	all	PA10	0.6	201.36	14.32	-	-	9.15
		PA11	0.7	188	13.18	-6.63	-7.96	17.6
	distance D	P2D10	0.6	231	17.15	-	-	8.13
		P2D11	0.7	246	17.9	6.49	4.37	15.64
	distance 1.5D	P3D10	0.6	219	16.2	-	-	6.33
		P3D11	0.7	240	17.62	9.58	8.76	12.16
NC	all	PN10	0.6	95	9.93	-	-	9.15
		PN11	0.7	86	9.25	-9.47	-6.84	17.6

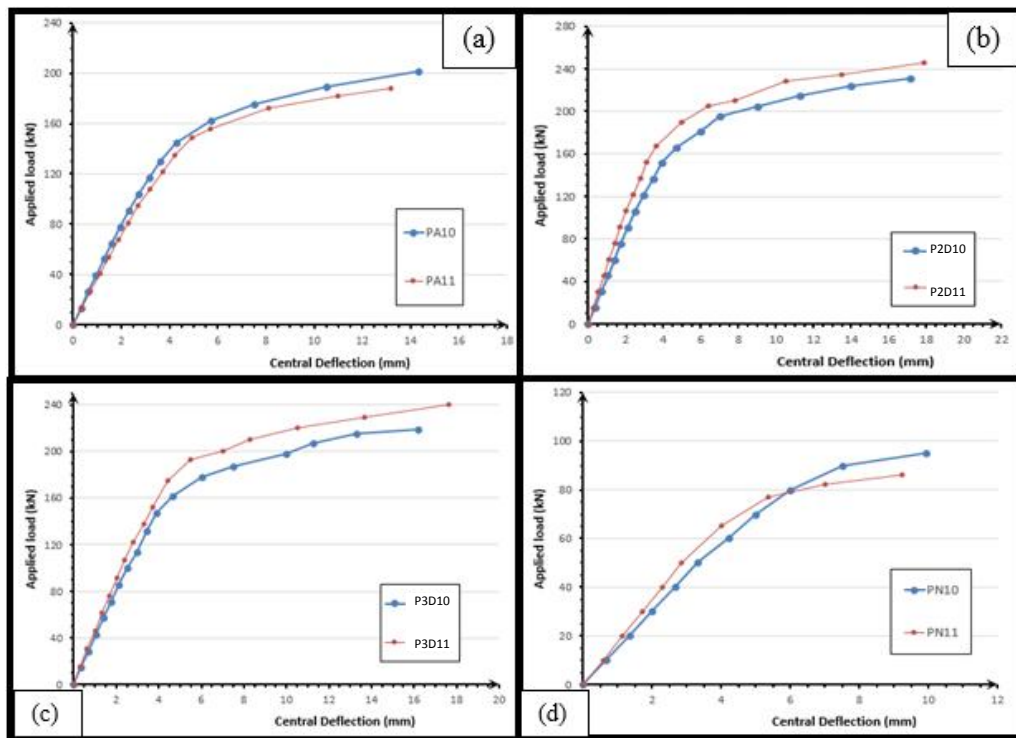


Figure (6): Comparison of load- deflection curves for: (a) PA10 and PA11, (b) P2D10 and P2D11, (c) P3D10 and P3D11, (d) PN10 and PN11.

- Effect of bubbles location

It was found that by removing bubbles from center of the slab at distance 2D and distance 3D the ultimate load will increase about (14.72%) and (8.76%) and the maximum deflection will also increase by about (19.76%) and (13.12%), respectively for (D/t) ratio of (0.6). Also, for (D/t = 0.7), the ultimate load will increase about (30.85%) and (27.65%) and the maximum deflection will also increase by about (35.81%) and (33.68%), for distance 2D and 3D, respectively.

Table (8) shows the specimens test results and Figures (7 and 8) represent comparison of load-deflection curves between (PA10, P2D10 and P3D10) and (PA11, P2D11 and P3D11), respectively.

Table (8): Effect of bubbles location on the ultimate load carrying capacity and maximum central deflection.

Slab Type	(D/t) ratio	Bubbles location	Slab designation	P_u (kN)	δ_u (mm)	% increase in P_u	% increase in δ_u	% weight reduction
RPC	0.6	all	PA10	201.36	14.32	-	-	9.15
		distance 2D	P2D10	231	17.15	14.72	19.76	8.13
		distance 3D	P3D10	219	16.2	8.76	13.12	6.33
	0.7	all	PA11	188	13.18	-	-	17.6
		distance 2D	P2D11	246	17.9	30.85	35.81	15.64
		distance 3D	P3D11	240	17.62	27.65	33.68	12.16

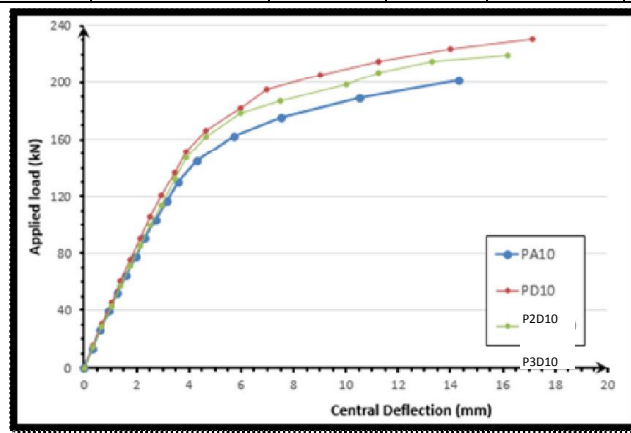


Figure (7): Comparison of load- deflection curves for PA10, P2D10 and P3D10.

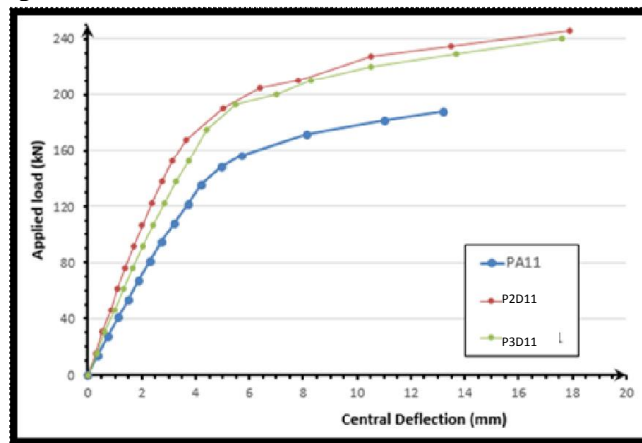


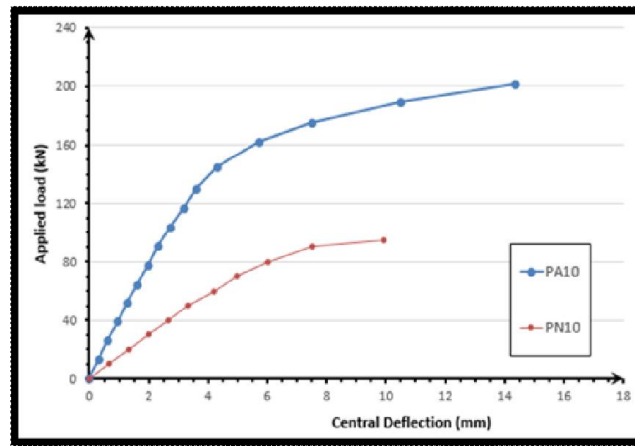
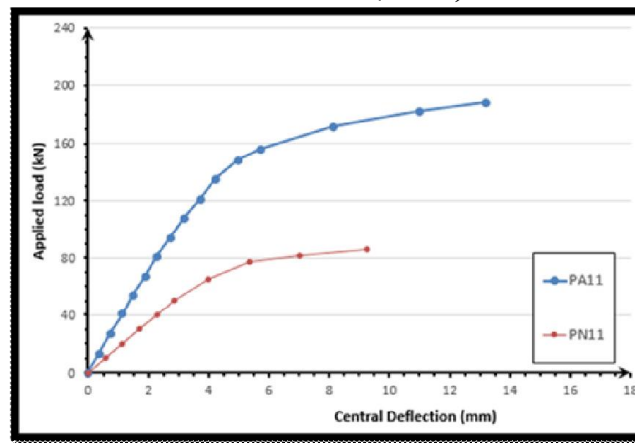
Figure (8): Comparison of load- deflection curves for PA11, P2D11 and P3D11.

- Effect of concrete type

It was found that by changing RPC to NC in the slabs the ultimate load capacity and the maximum deflection will decrease significantly due to the great compressive and tensile strength as well as great ductility. The decreases in the ultimate load was about (52.82%) and (54.25%) and in deflection was about (30.65%) and (29.81%) for (D/t =0.6 and 0.7), respectively. Table (9) shows the specimens test results and Figures (9 and 10) represent comparison of load-deflection curves between (PA10 and PN10) and (PA11 and PN11), respectively.

Table (9): Effect of type of concrete on the ultimate load carrying capacity and maximum deflection.

(D/t) ratio	Concrete type	Slab designation	P_u (kN)	δ_u (mm)	% decrease in P_u	% decrease in δ_u
0.6	RPC	PA10	201.36	14.32	-	-
	NC	PN10	95	9.93	52.82	30.65
0.7	RPC	PA11	188	13.18	-	-
	NC	PN11	86	9.25	54.25	29.81

**Figure (9): Comparison of load- deflection curves for slab made of RPC (PA10) and NC slab (PN10).****Figure (10): Comparison of load- deflection curves for slab made of RPC (PA11) and NC slab (PN11).****- Effect of bubbles**

From experimental test result it was found that using solid slab will increase both ultimate load and maximum deflection by about (5.28%) and (10.75%) compare to bubbled slab, respectively. Figure (11) shows comparison of load-deflection curves between solid slab (PS) and bubbled slab (PA10).

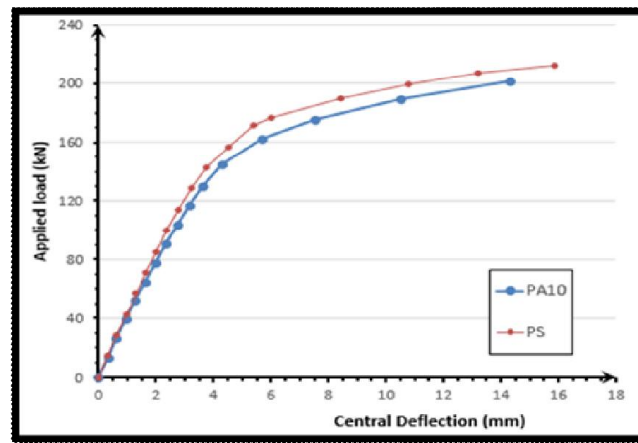


Figure (11): comparison of load-deflection curves for bubbled slab (PA10) and solid slab (PS) with 10 cm slab thickness.

- Crack Patterns

Figures (12-20) illustrate the specimens' crack patterns and failure mode under ultimate load. All specimens showed punching shear failure mode with crack at every directions especially slabs with 10 cm thickness which had wider cracks in the punching failure zones.



Figure (12): Crack pattern ($D/t = 0.6$) (PA10).



Figure (13): Crack pattern ($D/t = 0.7$) (PA11).



Figure (14): Crack pattern ($D/t = 0.6$) (P2D10).



Figure (15): Crack pattern ($D/t = 0.7$) (P2D11).



Figure (16): Crack pattern ($D/t = 0.6$) (P3D10).



Figure (17): Crack pattern ($D/t = 0.7$) (P3D11).



Figure (18): Crack pattern ($D/t = 0.6$) (PN10).



Figure (19): Crack pattern ($D/t = 0.7$) (PN11).



Figure (20): Crack pattern at the ultimate load for continuous RPC solid slab and 10 cm slab thickness (PS).

6) Conclusions

RPC continuous bubbled slabs were tested to investigate the punching shear behavior such as ultimate load capacity and maximum deflection of these specimens. The following conclusions had been achieved:

- 1) The ultimate load and the maximum deflection depends on (D/t) ratio due to decrease in self weight of slabs, by increasing (D/t) the ultimate load as well as maximum deflection will increased up to (9.58%) and (8.76%), respectively, for slabs with solid section in the center of the slab, but for bubbled slab the ultimate load and maximum deflection decreases up to (9.47%) and (7.96%), respectively.
- 2) The stiffness of the bubbled slab is less than solid slab, and the reduction in weights reduces the shear resistance area of the slab. So, the solid slab has greater ultimate load and deflection by about (5.28%) and (10.75%), respectively.
- 3) By using NC compare to RPC the ultimate load along with maximum deflection will be decreased tremendously up to about (54.25%) and (30.65%), respectively.

- 4) By removing the bubbles from center of the slab the ultimate load increased up to (30.85%) compare to bubbled slabs due to increase in shear resistance area in these slabs.
- 5) Crack pattern of the slabs shows that all slab had punching shear failure, especially the slabs with 10cm thickness where the cracks were wider in the punching shear failure zones.

7) References

- A. Churakov (2014), *"biaxial hollow slab with innovative types of voids"*, Saint-Petersburg Polytechnical University, Russia.
- Amer M. Ibrahim, Nazar K. Ali, Wissam D. Salman (2013), *"flexural capacities of reinforced concrete two-way bubble-deck slabs of plastic spherical voids"*, Diyala journal of engineering sciences, Vol. 06, No. 02, p.p. 9-20.
- Dauriac, C. (1997), *"Special concrete may give steel stiff competition"*, The Seattle Daily, Journal of Commerce, website available at <http://www.djc.com/special/concrete97/10024304.html>.
- Harding P. (2004), *"BubbleDeck – Advanced Structure Engineering"*, BubbleDeck article, p.p. 4-7.
- Iraqi Specification No. 5 (1984), *"Portland Cement"*, Baghdad.
- Iraqi specification No. 45 (1984), *"Natural Sources for Gravel that is Used in Concrete and Construction"*, Baghdad.
- J.H. Chung, H.K. CHOI, S.C. LEE, J.K. Oh. and C.S. Choi (2009), *"An Analytical Study of the Impact of Hollow Sphere on Biaxial Hollow slab"*, Proceeding of annual conference of the architectural institute of Korea.
- J.H. Chung, N.K. Ahn, H.K. Choi. and C.S. Choi (2009), *"An analytical study of optimal hollow sphere shapes in hollow slab"*, Journal of the Korea institute for structural maintenance.
- Nasvik J. (2011), On the bubble: Placing concrete around plastic voids increases efficiency and reduces costs. Concrete Construction - World of Concrete. Vol. 56. Issue12. p.p. 20-22.
- N.P. Lee & D.H. Chisholm (2005), *"reactive powder concrete"*, study report No. 146.
- Rebentrost, M. Cavill, B. (2006), *"reactive powder concrete bridge"*, Austroads conference. Perth, Australia.
- Tina Lai (2009), *"structural behavior of bubble-deck slabs and their application to lightweight bridge decks"*, MSc Theses, Massachusetts institute of technology.