# Flexural Behavior of Continuous Bubbled Reinforced Reactive Powder Concrete Flat Slab

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## Abstract:

This paper presents an experimental investigation on flexural behavior of continuous bubbled reinforced Reactive Powder Concrete (RPC) flat slabs. Bubbled slab is one of the various types of voided slabs. It consist 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 are used to increase the building spaces dimensions by reducing self-weigh of the structure by using bubbled slabs and to decrease the structural members' dimensions by using RPC have been investigated together.

To study the flexural behavior of continuous bubbled flat slabs such as the ultimate load carrying capacity, central deflection and slabs crack pattern at the ultimate load, seven 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), type of loading (distributed and line load) 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 (7.36%, 5.46% and 16.52%) for RPC slabs under distributed load, line load and NC slabs, respectively. The solid slab increases the ultimate load about (4.05%) compare to bubbled slab.

Also, the line load decreases the ultimate load compare to distributed load by (3.45-5.16%) for different (D/t) ratio, and using the NC also decreases the ultimate load compare to RPC by (48-52.13%) for different (D/t) ratio.

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

## الخلاصة:

يهتم هذا البحث بدراسة تحمل الانثناء للبلاطات الخرسانية المستمرة الفقاعية ذات المساحيق الفعالة. البلاطات الفقاعية هي أحد انواع البلاطات المجوفة والتي تتكون من كرات بلاستيكية توضع بداخل الخرسانة والتي تقلل من الوزن الذاتي للبناية بمقدار 35%. من طرف أخر، 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 الانثناء للبلاطات المستمرة والمجوفة والمتمثل بـ (الحمل الاقصى، الانحراف المركزي وشكل التشققات)، تم اختبار سبعة 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)، طريقة التحميل (الحمل المنتشر والحمل الخطي) 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 (7.36%، 5.46% و16.52%) لبلاطات ذات المساحيق الفاعلة والمعرضة الى الحمل المنتشر، الحمل الخطي والبلاطة الخرسانة الاعتيادية، على التوالي. البلاطة الصلدة تزيد التحمل الاقصى بحدود (4.05%) مقارنة مع البلاطة المجوفة.

كذلك، التحميل الخطي يقلل من التحمل الاقصى مقارنة مع التحميل المنتشر بحدود (3.45-5.16%) لنسب المختلفة من قطر الكرة الى سمك البلاطة، وكذلك استخدام الخرسانة الاعتيادية تقلل من التحميل الاقصى مقارنة مع الخرسانة ذات المساحيق الفعالة بحدود (48-52.13%) لنسب المختلفة من قطر الكرة الى سمك البلاطة.

**الكلمات المفتاحية:** البلاطات المجوفة، تحمل الانثناء 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 ( 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 ( 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 ( 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, (Nasvic , 2011).
- Down stand beams and bearing walls eliminated: Quicker and cheaper erection of walls and services (Harding , 2004).
- Reducing overall costs: The material consumption will reduced and construction will be faster (Nasvic , 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 $CO_2$ emissions are due to cement production ( 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 ( Lee and Chisholm; 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,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 μm). Its gradation lies within zone (3) and its sulfate content conformed by Iraqi specification (I.Q.S 45/1984).

***- 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).

***- 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 $m^3$ 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 (mm2) | weight (kg/m) | density (kg/m3) | E (GPa) | Yield strength Fy (MPa) | Yield strain | Ultimate strength Fu(MPa) |
|---|---|---|---|---|---|---|---|
| ϕ 6 | 28.3 | 0.222 | 7844.5 | 200 | 480 | 0.0024 | 550 |

**4.2 Specimens Description**

The tested continuous bubbled slabs were contained of seven 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), type of loading (distributed load and line load) 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) | Type of Loading |
|---|---|---|---|---|---|---|
| S1 | B10 | RPC | 100 | 60 | 0.6 | distributed load |
| S2 | B11 | RPC | 110 | 77 | 0.7 | distributed load |
| S3 | BS | RPC | 100 | - | solid | distributed load |
| S4 | BL10 | RPC | 100 | 60 | 0.6 | line load |
| S5 | BL11 | RPC | 110 | 77 | 0.7 | line load |
| S6 | BN10 | N | 100 | 60 | 0.6 | distributed load |
| S7 | BN11 | N | 110 | 77 | 0.7 | distributed load |

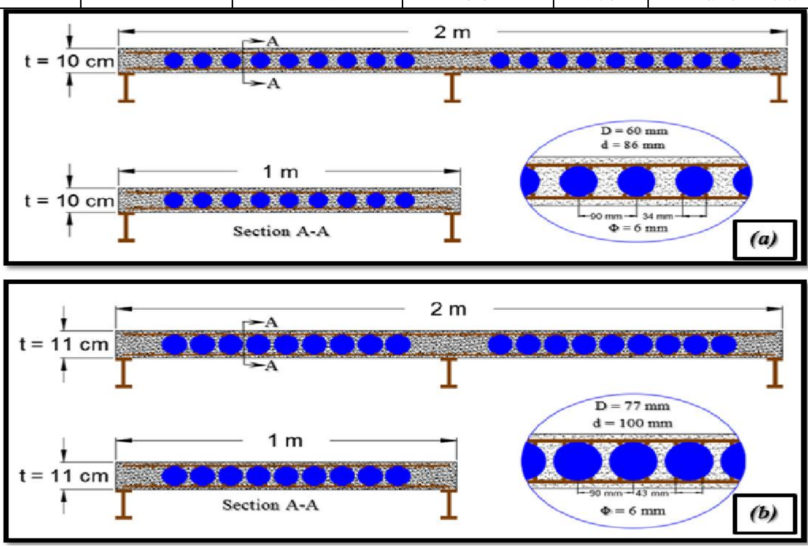


**Figure (1): Schematic Representation of Slabs.**

(a) Slabs dimensions and bubbles spacing for (0.6) (D/t) ratio.
(b) Slabs dimensions and bubbles spacing for (0.7) (D/t) ratio.

## 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 and strength.
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/m3) | fine sand (kg/m3) | silica fume (%) | silica fume content (kg/m3) | polymer fiber content (kg/m3) | w/c ratio | SP content liter/m3 |
|---|---|---|---|---|---|---|---|
| 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 $m^3$). 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.**

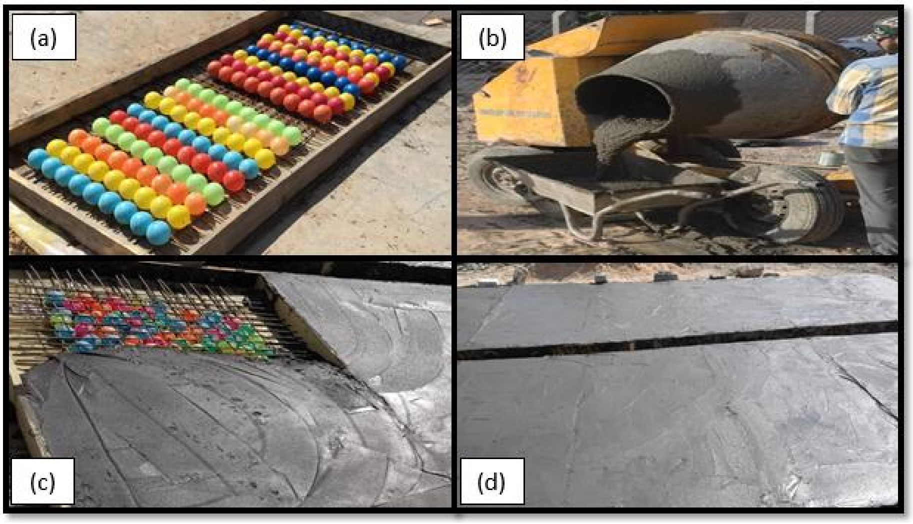


*Figure (2):* **Preparation of test specimens steps: (a) Placing bubbles on top bottom steel mesh inside the mold. (b) Pouring concrete after compilation of mixing process. (c) Pouring concrete into the molds after placing top steel mesh. (d) Slabs specimens after casting and smoothing the finished surface.**

***- Concrete Curing***

The curing process was started after 24 hours of casting by submerging all specimens in hot water at about $60C^0$ 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* $kg/m^3$ | $\upsilon$ | $F_t$ *MPa* |
|---|---|---|---|---|
| 103.7 | 40 | 2600 | 0.2 | 7.85 |

**Table (6): Mechanical Properties of Normal Concrete.**

| $f'_c$ *MPa* | *E* *GPa* | *Density* $kg/m^3$ | $\upsilon$ | $F_t$ *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 was used. The steel beam performed two types of loading, as described below:

1) Steel beam with five point loads on each slab which was considered as distributed load, as shown in Figure (3-b).

2) Steel beam with three point loads on each slab which was considered as line load, as shown in Figure (3-c).

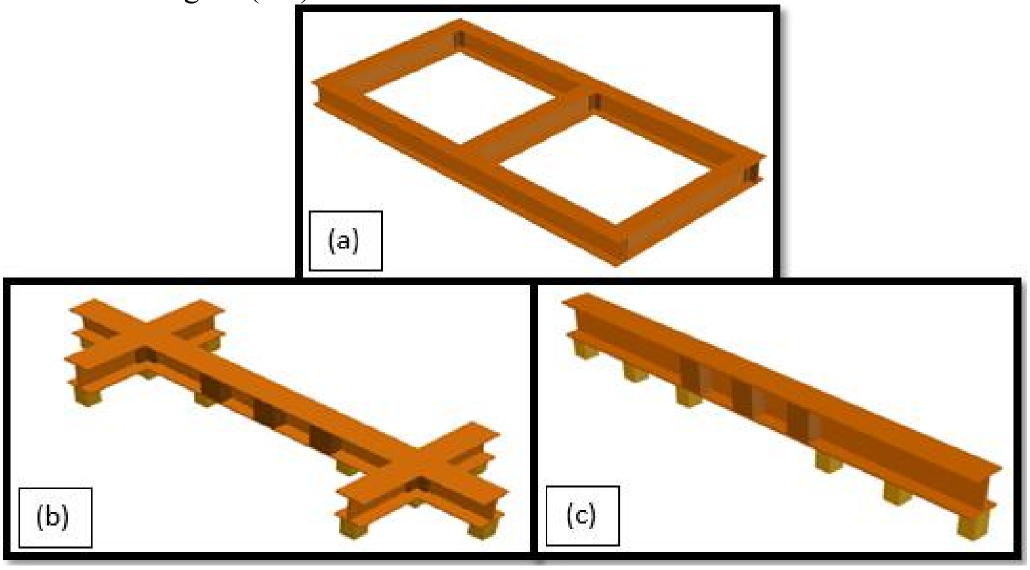


**Figure (3): (a) Perspective View of Steel Support Bed.**
**(b) Loading steel beam with five pointed loads.**
**(c) Loading steel beam with three pointed loads.**

***- 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 due to increase in cross section area about (7.36%), (5.46%) and (16.52%) for RPC slabs under distributed load, line load and NC slabs, respectively. But, maximum deflection was decreased for these slabs about (4%), (6.89%) and (4.11%), respectively.

Table (7) shows the specimens test results and Figures (6-8) represent comparison of load-deflection curves between (B10 and B11), (BL10 and BL11) and (BN10 and BN11), respectively.

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

| *Slab Type* | *Load Type* | *Slab designation* | *(D/t) ratio* | *$P_u$ (kN)* | *$\delta_u$ (mm)* | *% increase in $P_u$* | *% decrease in $\delta_u$* | *% weight reduction* |
|---|---|---|---|---|---|---|---|---|
| RPC | distributed | B10 | 0.6 | 246.5 | 11.64 | - | - | 9.15 |
| | | B11 | 0.7 | 264.66 | 11.17 | 7.36 | 4 | 17.6 |
| | line load | BL10 | 0.6 | 238 | 13.05 | - | - | 9.15 |
| | | BL11 | 0.7 | 251 | 12.15 | 5.46 | 6.89 | 17.6 |
| NC | distributed | BN10 | 0.6 | 118 | 8.5 | - | - | 9.15 |
| | | BN11 | 0.7 | 137.5 | 8.15 | 16.52 | 4.11 | 17.6 |

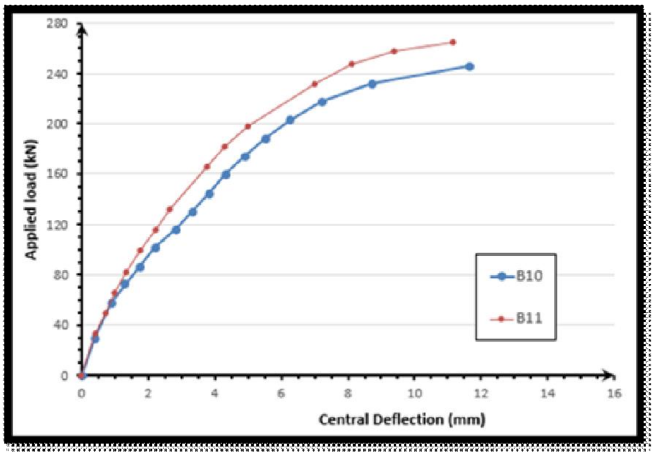


**Figure (6): Comparison of load- deflection curves for B10 and B11.**

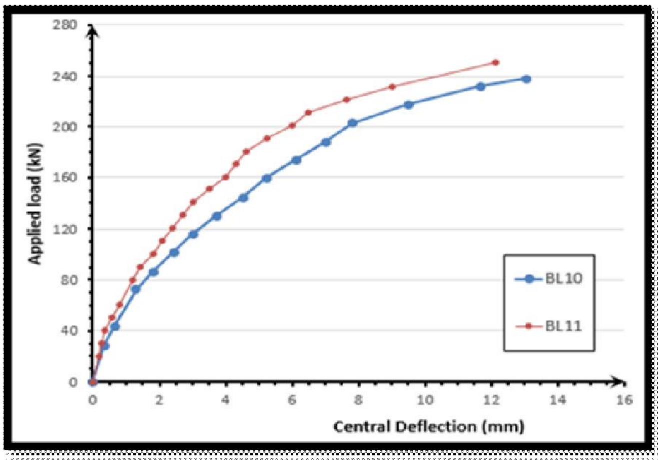


**Figure (7): Comparison of load-deflection curves for BL10 and BL11.**

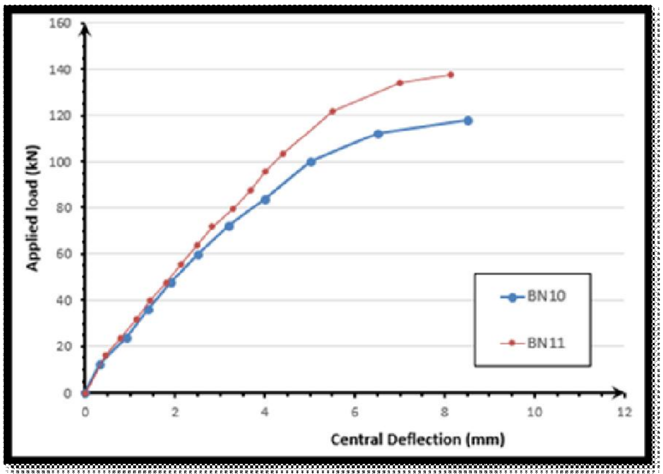


**Figure (8): Comparison of load-deflection curves for BN10 and BN11.**

- ***Effect of type of loading***

When the loading type changes from distributed load to line load, the ultimate load capacity decrease due to concentration of the pointed load by about (3.44%) and (8.86%), but the maximum deflection increases about (15.97%) and (7.43%) for (D/t=0.6 and 0.7), respectively.

Table (8) shows the specimens test results and Figures (9 and 10) represent comparison of load-deflection curves between (B10 and BL10) and (B11 and BL11), respectively.

**Table (8): Effect of type of loading on the ultimate load carrying capacity and maximum deflection.**

| *Slab Type* | *(D/t) ratio* | *Loading Type* | *Slab designation* | *$P_u$ (kN)* | *$\delta_u$ (mm)* | *% increase in $P_u$* | *% increase in $\delta_u$* |
|---|---|---|---|---|---|---|---|
| RPC | 0.6 | distributed | B10 | 246.5 | 11.64 | - | - |
| | | line load | BL10 | 238 | 13.05 | -3.45 | 12.11 |
| | 0.7 | distributed | B11 | 264.66 | 11.17 | - | - |
| | | line load | BL11 | 251 | 12.15 | -5.16 | 8.77 |

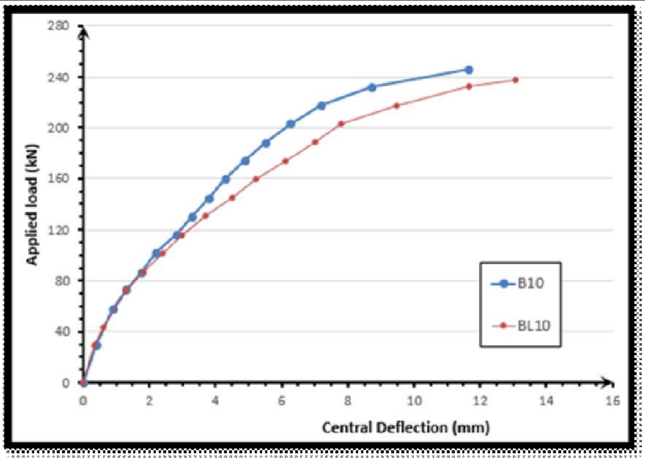


**Figure (9): comparison of load- deflection curves for (B10) under distributed load and line load (BL10) (D/t =0.6).**

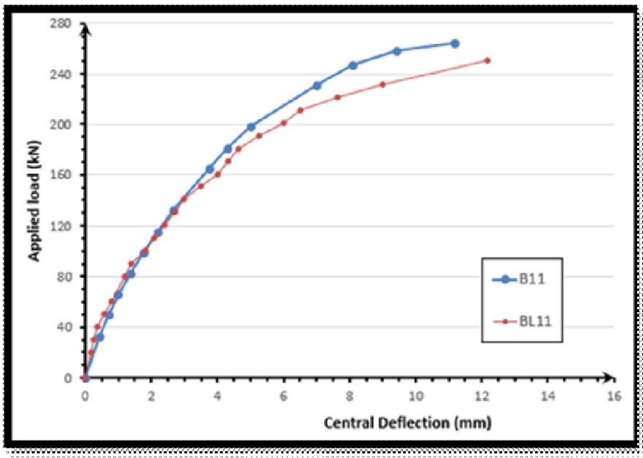


**Figure (10): comparison of load- deflection curves for (B11) under distributed load and line load (BL11) (D/t =0.7).**

***- Effect of concrete type***

It was found that by changing NC to RPC in the slabs the ultimate load capacity and the maximum deflection will increase significantly due to the great compressive and tensile strength as well as great ductility. The increases in the ultimate load was about (108.9%) and (92.48%) and in deflection was about (36.94%) and (37%) for (D/t =0.6 and 0.7), respectively. Table (9) shows the specimens test results and Figures (11 and 12) represent comparison of load-deflection curves between (B10 and BN10) and (B11 and BN11), 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)* | *$\delta_u$ (mm)* | *% increase in $P_u$* | *% increase in $\delta_u$* |
|---|---|---|---|---|---|---|
| 0.6 | NC | BN10 | 118 | 8.5 | - | - |
| | RPC | B10 | 246.5 | 11.64 | 108.9 | 36.94 |
| 0.7 | NC | BN11 | 137.5 | 8.15 | - | - |
| | RPC | B11 | 264.66 | 11.17 | 92.48 | 37 |

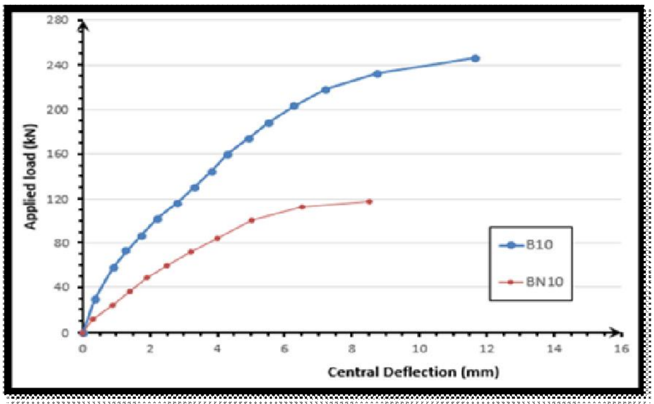


**Figure (11): comparison of load- deflection curves for Slab made of RPC (B10) and slab made of NC (BN10) (D/t =0.6).**

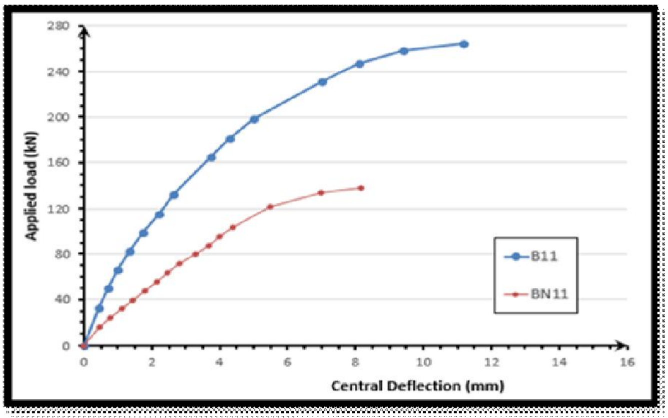


**Figure (12): comparison of load-deflection curves for slab made of RPC (B11) and slab made of NC (BN11) (D/t =0.7).**

***- Effect of bubbles***

From experimental test result, it was found that the using solid slab will increase both ultimate load and maximum deflection by about (4.05%) and (23.5%) compare to bubbled slab, respectively. Figure (13) shows comparison of load-deflection curves between solid slab (BS) and bubbled slab (B10).

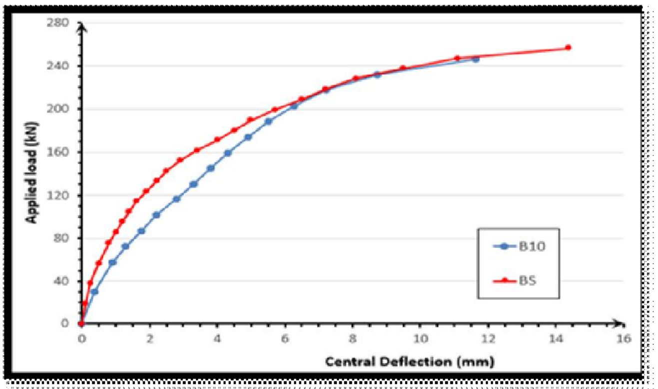


**Figure (13): comparison of load-deflection curves for bubbled slab (B10) and solid slab (BS) with 10cm slab thickness.**

***- Crack Patterns***

Figures (14-20) illustrates the specimens' crack patterns and failure mode under ultimate load. All specimens with (D/t = 0.7) and solid slab, showed flexural failure mode with crack at every directions. All the specimens with (D/t = 0.6), showed shear failure at the slabs edges and in the mid-section (BL10) along with flexural failure. This may be due to relatively smaller cross section area than (D/t = 0.7).


**Figure (14): Crack Pattern (D/t =0.6) (B10).**


**Figure (15): Crack Pattern (D/t =0.7) (B11).**

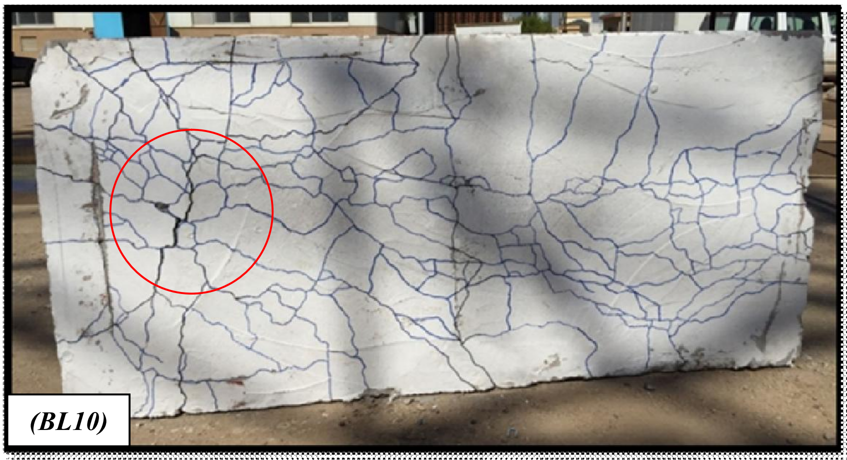


**Figure (16): Crack Pattern (D/t =0.6) (BL10).**


**Figure (17): Crack Pattern (D/t =0.7) (BL11).**

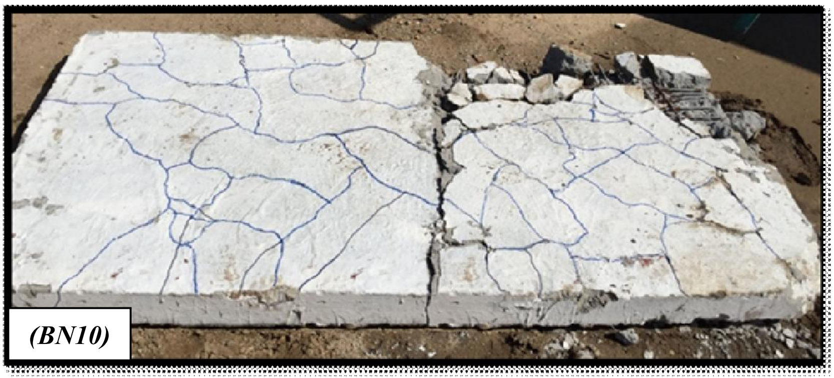


**Figure (18): Crack Pattern (D/t =0.6) (BN10).**

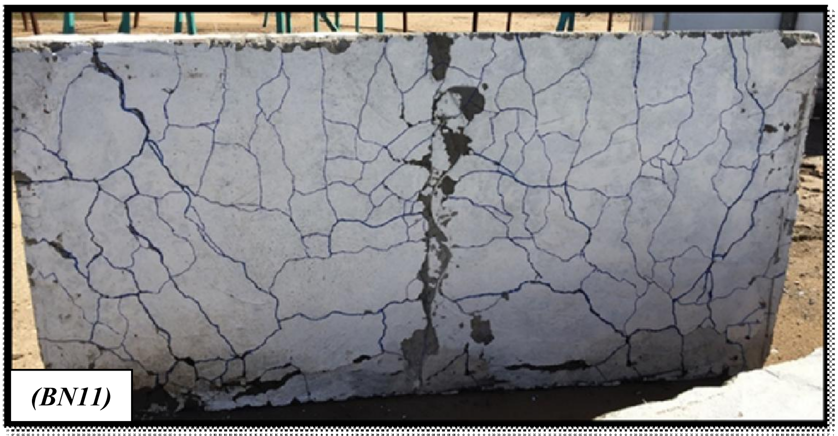


**Figure (19): Crack Pattern (D/t =0.7) (BN11).**

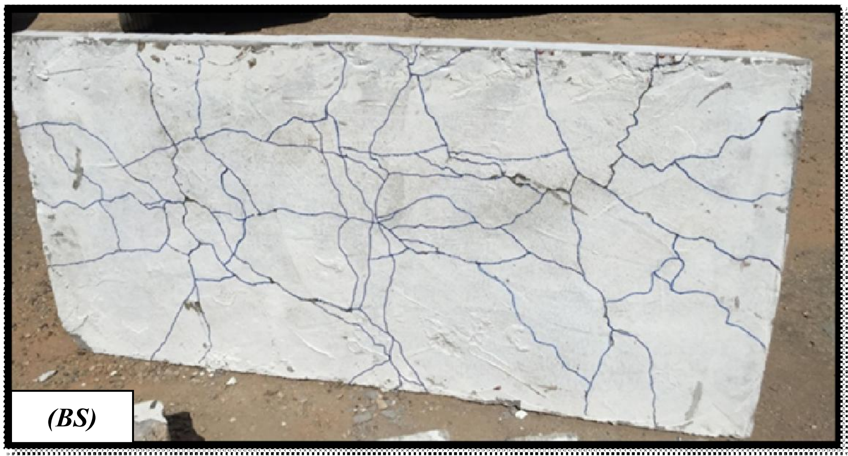


**Figure (20): Crack Pattern solid RPC slab (t = 10 cm) (BS).**

## 6 Conclusions

RPC continuous bubbled flat slabs were tested to investigate the flexural 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 increased up to (16.52%) and the maximum deflection decreased up to (6.89%).
2) The stiffness of the bubbled slab is less than solid slab, but the reduction in self-weight for bubbled slab seems to reduce the difference in stiffness when the load is increased but at the end the solid slab increases both ultimate load and maximum deflection by about (4.05%) and (23.5%), respectively.
3) Test results shown that by using RPC compare to NC the ultimate load along with maximum deflection increased tremendously up to about (108.9%) and (37%), respectively.
4) By changing the type of loading from distributed to line load, the slabs experienced more concentrated pressure due to less applied point loads and that causes the drop in ultimate load value up to (5.16%), since the bubbled slabs strength in shear is less than their flexural strength. But the three pointed load make the slabs to have more deflection up to (12.11%) due to concentration of applied load on center slabs.
5) Crack pattern of the slabs shows that all slab with (D/t =0.7) and solid slab had flexural failure mode while the slabs with (D/t = 0.6) along with flexural failure

experienced shear failure at slabs edges and slab's center for slab subjected to line load.

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