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THE EFFECT OF BALLS SHAPES AND SPACING ON STRUCTURAL BEHAVIOUR OF REINFORCED CONCRETE BUBBLED SLABS

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Abstract: Reinforced concrete slab with plastic voids (Bubbled-Deck system) is a new type of slabs which has two-dimensional arrangement of voids within the slab that is developed to decrease the slab self-weight while maintaining approximately the same load carrying capacity as it compared with the solid slabs. Plastic voided slabs have the ability to reduce the concrete amount by about 30 percent, this reduction is so important in terms of cost saving and enhancement the structural performance. This research presents experimental study to investigate the effect of ball shapes (spherical and elliptical) and spacing between balls in cross section (25 and 70mm) on the strength and behaviour of this kind of slabs. The bubbles were made using recycled plastic balls. The experimental program consists of casting and testing five slabs with dimensions of 1850mm×460mm×110 mm. The experimental results show that the bubbled slabs (containing spherical and elliptical balls) have about 90% to 96% of the ultimate load of the solid slab and an increase in the deflection at ultimate load by 7.8% to 21%, at the same time the first crack load decreases by about 6.7% to 16% as it compared with that of the solid slab. Also the results show that bubbled slabs having spherical balls are more efficient in bearing loads than that having elliptical balls with the same amount of concrete reduction.

Keywords: *Bubbled-Deck, spherical, elliptical*

تأثيرشكل الكرات والمسافة بينها على مقاومة وسلوك البلاطات الخرسانية المسلحة الحاوية على فجوات فقاعية

الخلاصة: تعتبر البلاطات الخرسانية المسلحة الحاوية على فجوات بلاستيكية نوعا جديدا من البلاطات الحاوية على نظام ثنائي الابعاد من الفراغات داخل البلاطة والتي تعمل عل انقاص وزن البلاطة الذاتي مع المحافظة بشكل تقريبي على نفس سعة التحمل بالمقارنة مع البلاطات الصلدة. ان البلاطات ذات الفجوات البلاستيكية لها القابلية على تقليل كمية الخرسانة المستخدمة بحوالي 30% و هذا التقليل ذو اهمية كبيرة من حيث توفير الكلفة وتحسين الاداء الانشائي. هذا البحث يعرض الدراسة العملية لتخمين تأثير شكل الكرة (كروية اوالبيضوية) و المسافة بين الكرات في المقطع العرضي (25 ملم او70 ملم) على مقاومة وتصرف هكذا نوع من السقوف. البرنامج العملي تضمن صب وفحص خمسة سقوف بأبعاد (1850ملم× 460ملم × 110ملم). بينت النتائج التجريبية ان البلاطات الحاوية على فجوات فقاعية (كروية و بيضوية) تمتلك قوة تحمل تتراوح بين 90% الى 96% من تحمل البلاطة الصلدة و زيادة في الهطول عند الحمل الاقصى بمقدار 7.8% الى 21%، وفي الوقت نفسه حمل التشقق الاولي يقل بحوالي 6.7% الى 16% مقارنة بالبلاطة الصلدة. كذلك بينت النتائج بأن البلاطات الحاوية على كرات كروية اكثر كفاءة في تحمل الاحمال من تلك التي تحتوي على كرات بيضوية مع نفس كمية الكونكريت المختزلة.

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1. Introduction

The slab is one of the most important structural members to make a space in buildings, and it is one of the largest members consuming concrete. When the span of a building increases, the deflection of slab increases too and that leads to an increase in its thickness, this makes the slab heavier and increases its columns and foundation size. All of these factors make the building consumes more materials such as steel and concrete [1].

For decades, many attempts had been made to create biaxial hollow slabs for the sake of weight reduction. Many attempts had used a lighter materials such as expanded polystyrene which was laid between the bottom and the top of reinforcement, and other types including waffle slabs/grid slabs. Only waffle from these types has a certain use in the market, but its use is very limited because of reduction in resistance of shear, local punching and fire [2].

In 1990s, a new system, the so called Bubble-Deck system was invented by Jorgen Breuing, eliminating the above problems. The Bubble-Deck system uses balls made of recycled plastic to create air voids while providing strength through arch action. These bubbles can decrease the dead weight by about 30% and increase the capacity up to 100% with the same thickness [3].

The Bubble-Deck system offers a wide range of advantages in building design and during construction. There are a numbers of green attributers including; reduction in total construction materials, use of recycled material, lower energy consumption, and a reduction in CO_2 emissions, a less transportation and crane lifts that make the Bubble-Deck more environmentally friendly than other concrete construction techniques [4].

2. Experimental work

2.1 Materials

2.1.1 Cement

The type of cement which is used in this work was the Ordinary Portland cement (type I). The chemical composition and physical properties are conforming to the requirements of the Iraqi Standard Specification No.5 [5].

2.1.2 Fine Aggregate (sand)

The fine aggregate which is used in this work has fineness modulus of 2.38. The grading and physical properties of fine aggregate are conformed to the limits of the Iraqi specification No.45 [6].

2.1.3 Coarse Aggregate

In this study, natural gravel is used as coarse aggregates with a maximum size of (12.5mm). Natural gravel is obtained from Assidor region. The gravel washed many times and dried on air. The physical properties and grading of this aggregates satisfied the requirements of the Iraqi specification No.45 [6].

2.1.4 Admixture

There are two types of admixture used in this present study:

- Superplasticizer

High Performance Superplasticizer Concrete Admixture (HPSCA), used throughout this work with trade name (Viscocrete-5039). It is a third generation of high performance dual action super plasticizer for concrete which can produce self-compacting concrete. Also, it is free from chloride and complies with (ASTM C494type G and F). A substantial increase in slump and flow ability without segregation was observed when the concrete mixture contains superplasticizer.

- Lime stone

In the present experimental work, crushed LimeStone Powder (LSP) brought from local market was used as a filler for concrete production. Filler is used in SCC to increase the amount of fine material in the mixture, so enhance its cohesiveness and better segregation resistance. The particle size of LSP is less than 0.125 mm according to EFNARC specification [7].

2.1.5 Steel Reinforcement

For all slabs, deformed steel bar are used as the steel reinforcement at the top and the bottom of the slabs. The major reinforcement has a size of Ø10 mm with a yield stress of 470Mpa, while the minor reinforcement size is Ø4mm with a yield stress of 390Mpa.

2.2 Specimens Description

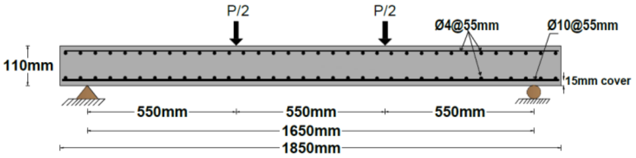
The experimental program of this study consists of casting and testing five slabs with dimensions of (1850mm×460mm×110 mm). One of these slabs is a solid slab (without balls). Two of them contain spherical balls with diameters of 80mm (the clear spacing between the balls in the cross section are 25mm and 70mm), while the last two slabs have elliptical balls with diameters of (small diameter 60mm and large diameter 80mm) and the clear spacing is similar to that of spherical bubbled slabs. Table (1) and Figure (1) show the details of the tested slabs of this study.

2.3 Concrete

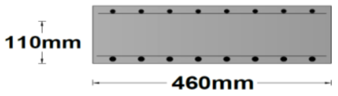
All the tested slabs are fully made with Self-Compacted Concrete (SCC) with a design compressive strength of 30MPa. The concrete mixture quantities are presented in Table 2. For each series of casting, the specified compressive strength is measured by testing three cylinders of dimension (150mm ×300mm).

Table 1. Details of the tested slabs

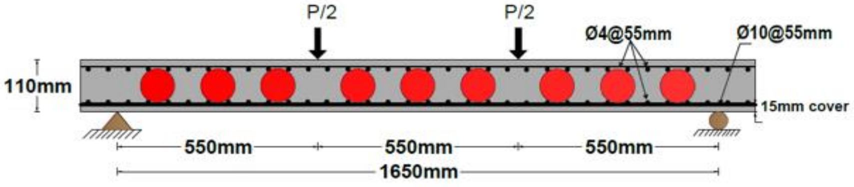
Slab code	Type of construction	Shape of balls	Spacing between balls in cross section	Reduction in concrete volume
SS	Ordinary construction	---	----	----
BS_{sp70}	Simple bubble slab	Spherical	70mm	15%
BS_{sp25}		Spherical	25mm	20%
BS_{elp70}		Elliptical	70mm	15%
BS_{elp25}		Elliptical	25mm	20%



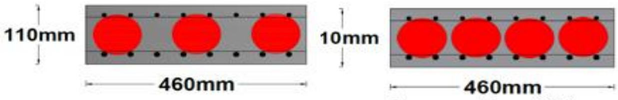
Longitudinal section of SS



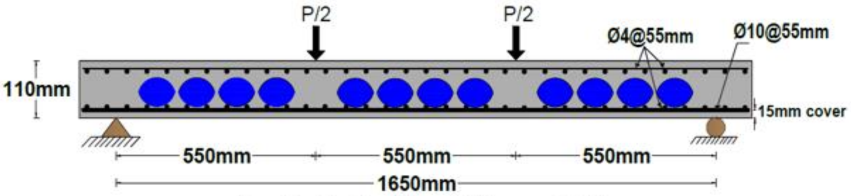
Cross section of SS



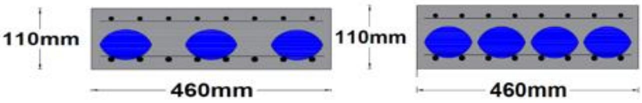
Longitudinal section of BS_{sp70} and BS_{sp25}



Cross section of BS_{sp70} **Cross section of BS_{sp25}**



Longitudinal section of BS_{elp70} and BS_{elp25}



Cross section of BS_{elp70} **Cross section of BS_{elp25}**

Fig. 1 Details of the tested slabs.

Table 2. Concrete mixture quantities per cubic meter

Material	Cement	Sand	Gravel	Limestone	Water	Superplasticizer
Quantities Kg/m^3	300	850	670	230	200	1.85

2.4 Results and Discussions

2.4.1 Ultimate load capacity

The observed results of the tested slabs of this study are listed in Table 3. Test result shows that there is a little reduction in the ultimate loads of the bubbled slabs (BS_{sp70}, BS_{sp25}, BS_{elp70} and BS_{elp25}) as compared with the solid slab by about 4.4%, 10.5%, 7.9% and 19% respectively. The little value of this reduction is attributed to the presence of the plastic balls which are placed at the mid depth of the bubbled slabs sections where the stress is minimum. This is a good benefit in decreasing the slab weight and maintaining the ultimate strength at the same time. The ultimate loads of the (BS_{sp70} and BS_{elp70}) are higher than that of the (BS_{sp25} and BS_{elp25}) by about 6.5% and 9.5% respectively.

This increase in ultimate loads can be attributed to the smaller amount of reduced concrete with a larger clear spacing ,so that the slabs (BS_{sp70} and BS_{elp70}) maintain higher percentage of ultimate load than those with a smaller clear spacing (BS_{sp25} and BS_{elp25}).

Furthermore, bubbled slabs with spherical balls (BS_{sp70} and BS_{sp25}) have better load bearing capacity than those with elliptical balls (BS_{elp70} and BS_{elp25}) by 3.7% and 9.7% respectively with the same amount of concrete reduction. This increase in ultimate load belongs to that bubbled slabs with spherical balls are more efficient in load stresses distribution than bubbled slabs with elliptical balls.

Table 3. Data observed from the tested slabs

Slabs code	Yield load P_y (kN)	Yield deflection Δ_y (mm)	% Increase in Δ_y	Ultimate load P_u (kN)	% Decrease in P_u	Ultimate deflection (mm)	Ductility ratio Δ_u/Δ_y
SS	75	11.6	---	115	---	28.4	2.5
BS_{sp70}	71	13	12	110	4.4	34.8	3
BS_{sp25}	71	13.9	19.9	103	10.5	24.2	1.74
BS_{elp70}	72	12.5	7.8	106	7.9	41.1	3.3
BS_{elp25}	69	14	20.7	93.2	19	25.4	1.8

2.4.2 Load-Deflection Relationship

The deflection is measured by using three dial gauges. One of these gauges is at the center and the other two are under the two loads of the tested slabs. The readings which is given by these gauges are recorded at each load increment. Fig. 2 and Table 3 show that at yield load, the deflections of bubbled slabs (BS_{sp70}, BS_{sp25}, BS_{elp70} and BS_{elp25}) are more than that of the solid slab by 12%, 19.9%, 7.8% and 20.7 % respectively. This increase is attributed to the presence of plastic balls in bubbled slabs, which leads to a decrease in the moment of inertia (I), and in term will decrease the flexural stiffness (EI) of bubbled slabs. Fig. 3 shows that the load-deflection curve for (BS_{sp25} and BS_{sp70}) is approximately the same at all loading stages, but the ultimate deflection of BS_{sp70} is more than that of BS_{sp25} by about 30.5%. This increase is due to large spacing between balls in BS_{sp70} which makes the failure to be a flexural, in contrast with BS_{sp25} which has a shear failure. In addition, the results show that changing the clear spacing in the cross section of bubbled slabs from 70mm (slabs BS_{sp70} and BS_{elp70}) to 25mm (slabs BS_{sp25} and BS_{elp25}) increases the deflection at yield load (Δ_y) by about 7.7% and 12% respectively, whereas the ultimate deflection decreases by 30.5% and 38.2% as shown in Fig. 4.

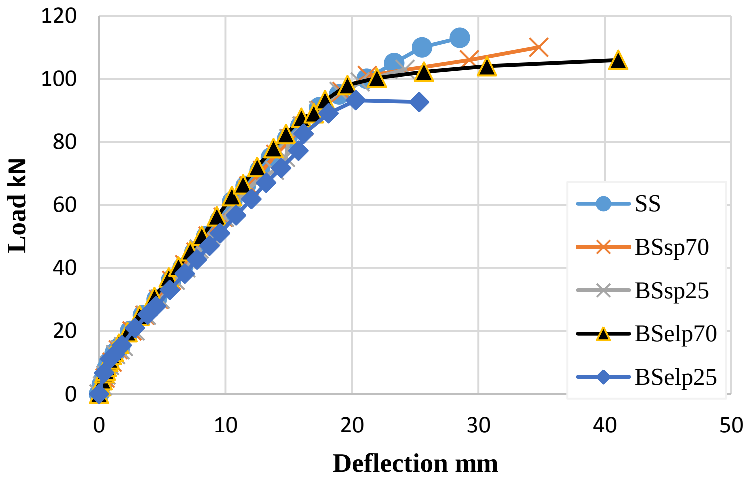


Fig. 2 Load-deflection curve of all slabs

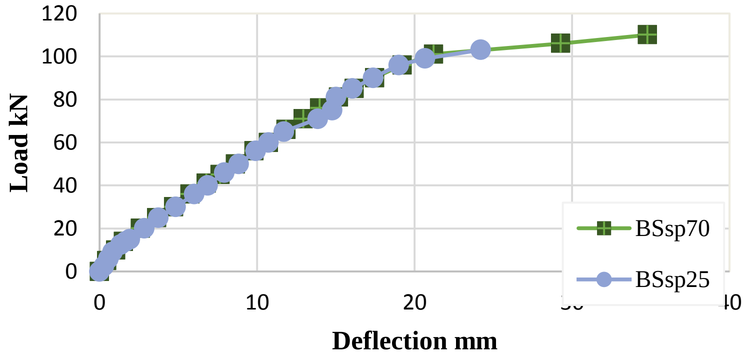


Fig. 3 Load-deflection curve of bubbled slabs containing spherical balls

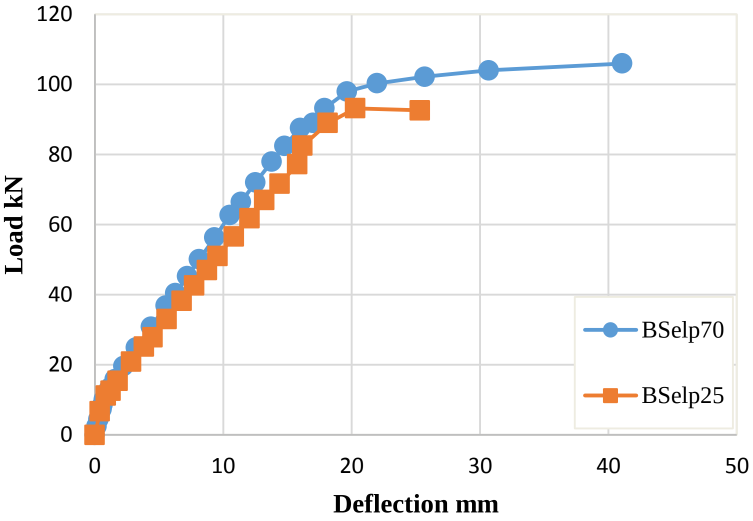


Fig. 4 Load-deflection curve of bubbled slabs containing elliptical balls

2.4.3 Average Concrete Surface Strain

Concrete surface strain was measured by using two strain gauge types (PFL-30-11-3L) installed at the middle of the top surface of the slab. The results show that bubbled slab specimens give an increase in the concrete surface strain over that of the solid slab. This is due to the presence of plastic balls that reduced the concrete volume in the compression zone of bubbled slab specimens. Slabs having a flexural failure (BS_{sp70} and BS_{elp70}) give a higher increase in compression strain than that with a shear failure (BS_{sp25} and BS_{elp25}) by about 23.3% and 36.5%. Fig. 5 shows the load-average concrete strain of all slabs.

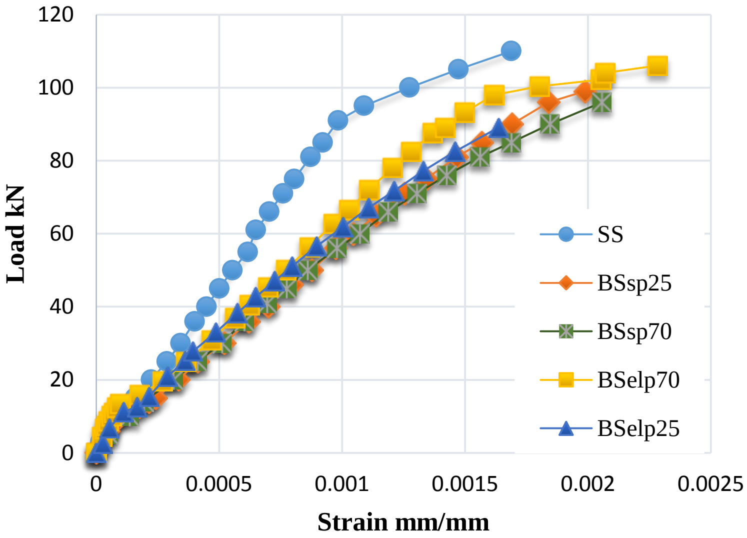


Fig. 5 Load-average concrete strain of all slabs

2.4.4 Steel reinforcement strain

Steel reinforcement strain was measured by using two electrical resistance strain gauge types (PFL-10-11-3L) placed in the middle of the two intermediate longitudinal reinforcing bars. Fig. 6 shows that the strain in steel reinforcement bars in all slab specimens is very small until the load of 15kN. After that, abrupt changes in strain readings were recorded. Bubbled slabs (BS_{sp70}, BS_{sp25}, BS_{elp70} and BS_{elp25}) have a decrease in ultimate strain of reinforcement bars by 1.2%, 31.85%, 24.53% and 96.2% from that of the solid slab. The bubbled slabs (BS_{sp70} and BS_{sp25}) and (BS_{elp70} and BS_{elp25}) are very close until the load failure. This proves that the spacing between balls in the cross section of bubbled slab doesn't affect the behaviour of strain but it does so on the ultimate strain magnitude. The strain at ultimate load (Ɛu) for bubbled slabs which have flexural failure (BS_{sp70} and BS_{elp70}) are more than those having a shear failure (BS_{sp25} and BS_{elp25}) by about 23.3 and 36.5% respectively.

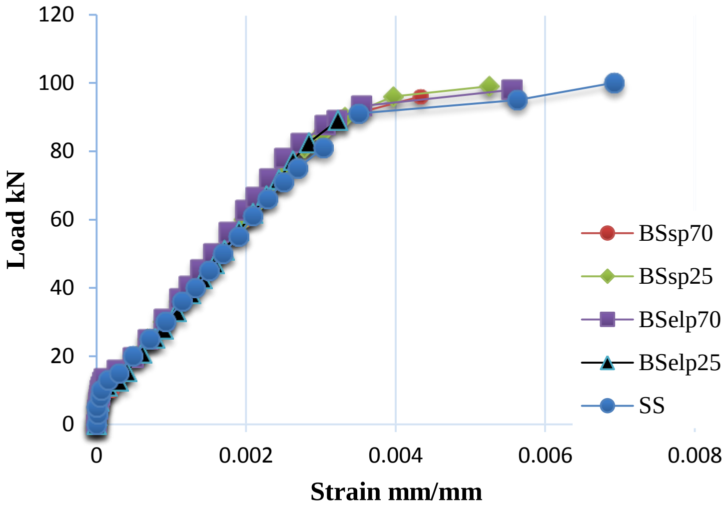


Fig. 6 Load-steel reinforcement strain of all slabs

2.4.5 Crack pattern and mode of failure

The initial crack of all tested slabs was first observed in the tension zone of the slab near the center of the slab. In the solid slab, first flexural crack is initiated at (15kN), at this stage of loading the tensile stress in concrete reaches the modulus of rupture value and cracking starts in the zone of maximum tensile stress. The first crack appears at 13%, 12.7%, 13.6%, 12.7% and 13.5% of the ultimate load of slabs SS, BS_{sp70}, BS_{sp25}, BS_{elp70} and BS_{elp25} respectively. The bubbled slabs BS_{sp70}, BS_{sp25}, BS_{elp70} and BS_{elp25} have a decrease in the first crack load when it is compared with the solid slab by about 6.7%, 6.7%, 10% and 16% respectively. This is due to the concrete volumes reduction in the tension zones which is belong to the presence of plastic balls. The mode of failure for SS, BS_{sp70} and BS_{elp70} is flexural, while shear failure occurs in BS_{sp25} and BS_{elp25} due to concrete component reduction that resists shear force (Vc). Fig. 7 illustrates the mode of failure and the crack pattern of all slab specimens in this study.

Fig. 7 Crack pattern and mode of failure of SS

Fig. 8 Crack pattern and mode of failure of BS_{sp70}

Fig. 9 Crack pattern and mode of failure of BS_{sp25}

Fig. 10 Crack pattern and mode of failure of BS_{elp70}

Fig. 7 Crack pattern and mode of failure of BS_{elp25}

5. Conclusions

1. The ultimate load shown by the slabs of 70mm spacing between balls (BS_{sp70} and BS_{elp70}) is near to that of the solid slab while the slabs of 25mm spacing (BS_{sp25} and BS_{elp25}) have lesser ultimate loads than that of the solid slab by about 10% and 19% respectively.
2. The bubbled slabs which have spherical balls (BS_{sp70} and BS_{sp25}) have higher ultimate loads than that having elliptical balls (BS_{elp70} and BS_{elp25}) by about 3.7% and 9.7% respectively.
3. The deflection at yield load (Δy) for bubbled slabs is slightly more than that in the solid slab.
4. The tensile strain in steel reinforcement and the compressive strain in the top face of concrete are greater in bubbled slabs than solid slab.
5. There is a decrease in the first crack load of bubbled slabs when compared with that of the solid slab by about (from 6.7% to 16%).

6. References

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