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STRUCTURAL BEHAVIOR OF REACTIVE POWDER CONCRETE VOIDED CYLINDRICAL SHELL SEGMENTS

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Abstract: Voided cylindrical shell is a sustainable reinforced concrete roof system. Two directions of the voids system with two types of the voids shape in each direction had been used in this experimental work. Circular and squared void shapes used as continuous voids in the uniaxial direction while spherical and cubic void shapes used as separate voids in the biaxial direction. The diameter of the circular or spherical void is (70mm) and an equivalent side length of about (62.5mm) was used for the squared or cubic voids. The experimental variables were included the type of the shell, direction of the voids, shape of the voids and a number of the steel reinforcing layers (bottom or top and bottom) . The cylindrical shells tested as simply supported under one-point load at the crown of the shell. By (37%) maximum reduction in the concrete volume, the ultimate load capacity decreased by (35%). As well as, use of the voids in the biaxial direction improved the structural behavior in comparison with the use of voids in the uniaxial direction as a hollow core section. The use of square section or cubic void shape gave a better structural performance than the use of circular section or spherical void shape in both directions.

Keywords: *Voided; Cylindrical; Shell; Reactive Powder Concrete.*

السلوك الانشائي لشرائح القشرة الاسطوانية الفجوية من خرسانة المسحوق الفاعل

الخلاصة : القشرة الاسطوانية ذات الفجوات هي نظام تسقيف مستدام من الخرسانة المسلحة. استخدم في هذا العمل نظامين من الفجوات أحادي وثنائي الأتجاه مع نوعين من شكل الفجوات في كل إتجاه. تم استخدم شكل المقطع المربع والدائري للفجوات المستمرة في النظام أحادي المحور والشكل المكعب والكروي في النظام ثنائي المحور. وقد تم استخدام قطر(70ملم) للفجوات الدائرية والكروية اما الفجوات المكعبة والمربعة فقد تم استخدام طول ضلع مكافئ (62.5 ملم). المتغيرات الرئيسية المدروسة في هذه البحث هي: نوع الاسقف القشرية ،اتجاه الفجوات، شكل الفجوات وعدد شبكات التسليح (تسليح سفلي فقط أم سفلي وعلوي). تم فحص نماذج الأسقف الأسطوانية كأسناد بسيط تحت قوة مركزة في أعلى القوس. بتقليل حجم الخرسانة المستخدمة بمقدار (37٪) كحد أعلى ، نقصت قابلية التحمل الأقصى بمقدار (35٪). فضلا عن ذلك، أدى استخدام الفجوات في النظام ثنائي الإتجاه إلى تحسين السلوك الإنشائي بالمقارنة مع استخدام الفجوات في النظام أحادي الاتجاه وكذلك بينت النتائج أن المقطع المربع أو الشكل المكعب للفجوات أعطى أداءا إنشائيا أفضل في كلا الإتجاهين من استخدام المقطع الدائري أو الشكل الكروي للفجوات.

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1. Introduction

The word shell refers to a spatial, curved structural member.
The enormous structural and architectural potential of shell structures is used in various fields of civil, architectural, mechanical, aeronautical and marine engineering.

The strength of the curved structure is efficient and economically used, for example to cover large areas without supporting columns [1]. A shell is a three-dimensional spatial structure made up of one or more curved slab or folded plates whose thickness are small compared to their other dimensions [2]. A shell may be called shallow when its rise is small compared with its plan dimensions.

The shallow shells have a ratio of the rise to the shorter side less than 0.2. Thin shells are determined as shells with a radius to thickness ratio (R/t) between 20 and 1000. By comparison the ratio of an egg is approximately 60, newfangled structures can achieve ratios exceeding 1000, which demonstrates the great load carrying ability of shells [3]. Shell structures are useful for reinforcing concrete components requiring high strength. The inherent curvature of shells allows for the decomposition of stress resultants in several directions, enabling a combination of membrane and bending action to obtain an increase in load carrying ability [4].

In addition to the special properties of the shell structures due to its geometry which make the shell withstands the external forces in spite of the small thickness, the attempts of minimizing the materials used in the concrete shell roofs for large spans are still important. This point is more effective when using expensive materials such as reactive powder concrete. On the other hand, the utilization of the voided concrete shell is important for achieving sustainability requirements by improving the insulation properties as well material minimization. Reactive powder concrete is characterized by extraordinary mechanical properties such as (high compressive and tensile strength, large modulus of elasticity) and it has excellent durability properties regarding corrosion of concrete and reinforcement (low permeability against liquids and gases, thus high resistance against the penetration of ions [5].

2. Background

Various attempts have been developed in the past to reduce the weight of concrete slabs, with maintaining the flexural strength of the slab. For this purpose, a part of the internal concrete near the neutral axis can be removed with necessity to connect the top and bottom faces of the slab to work as one unit and ensure the transfer of the stresses between the outer layers as the sandwich panels for example. The concrete in the top zone of the slab is requisite to form the compression block for flexural strength, and the concrete in the tension zone of the slab needs to bond with reinforcement to make the reinforcement effective for flexural strength. Biaxial voided and uniaxial voided (bubble and hollow core systems) were and are still used to reduce the self-weight of slab structures with long spans

[6,7]. The bubbled reinforced concrete slab system (biaxial voided), also known as a voided slab system, has been recently presented in Europe. This system consists of hollow plastic balls cast into the concrete to create a grid of voids inside the slab [8]. Several researchers [9-15] presented experimental and theoretical studies to investigate the punching shear and flexural strength capacities of voided slab. A considerable literature is available in the concrete shells, but the studies in voided concrete shells are nonexistent yet.

3. Experimental Work

The experimental program involves casting and test seven specimens of cylindrical shell of (1000 mm chord length, 1060mm length of the arch, 420 mm width and 100 mm thickness). Each cylindrical shell has two edges beams on both sides with dimensions of (200mm length, 420 mm width and 100 mm thickness). The geometry of the final shape of the cylindrical shell model is drawn in Fig. 1.

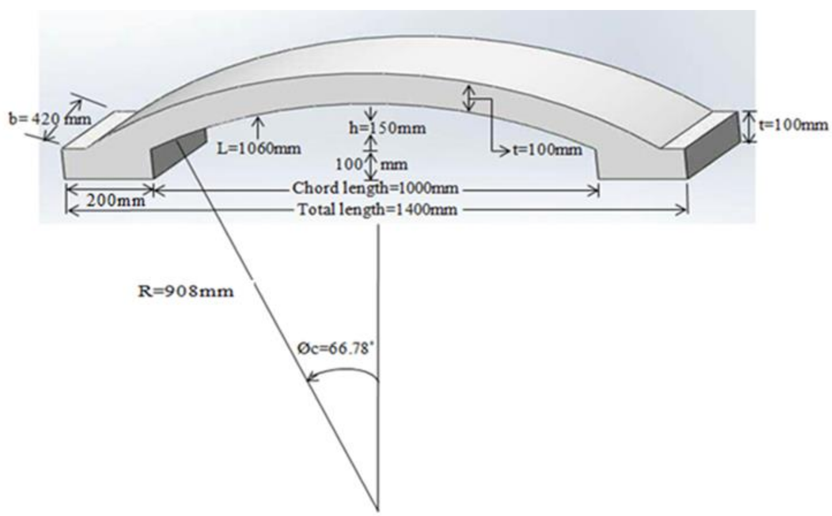

Figure 1. Geometry of the cylindrical shell model

The main experimental parameters in this study are; type of shell (solid and voided), type of voided shell; biaxial (bubbled) or uniaxial (hollow), type of void shape (circular or squared) and number of layers of reinforcement. High density Polypropylene spherical balls and pipes were used to make spherical voids in the biaxial direction and circular continuous voids in the uniaxial direction respectively, while cork cubes and blocks were used to make cubic voids in the biaxial direction and squared continuous voids in the uniaxial direction respectively. Details of these parameters are shown in the Table 1. The mixture of reactive powder concrete (RPC) is designed with a high ratio of silica fume, low percentages of the water to cement ratio (W/C) made low ratios of super plasticizer, and the presence of micro steel fibers.

A compressive strength in the mortar is affected by sand to cement ratio (S/C). The present study adopted the (S/C) equal to 1.0 as it was found to be very effective for the optimization of the mortar mixture with super plasticizer of (6%) from a weight of cementations materials [16-20]. The mixture used in this investigation with percentages of micro steel fibers (1%) of the total volume as shown in the "Table 2".

Table 1. Experimental parameters details

Specimen	Shell Coding*	Type of Voided Shell	Void Shape	Reinforcement Layers
1	S-B	Solid	-	Single (bottom)
2	V-Uni-Cir-B	Voided (Uniaxial)	Circular	Single (bottom)
3	V-Uni-Cir-TB	Voided (Uniaxial)	Circular	Double (top & bottom)
4	V-Uni-Squ-B	Voided (Uniaxial)	Squared	Single (bottom)
5	V-Uni-Squ-TB	Voided (Uniaxial)	Squared	Double(top & bottom)
6	V-Bia-Sph-B	Voided (Biaxial)	Spherical	Single (bottom)
7	V-Bia-Cub-B	Voided (Biaxial)	Cubic	Single (bottom)

S: solid, V: voided, B: bottom, T: top, Uni.: Uniaxial, Bia.: Biaxial, Cir.: Circular, Squ.: Squared, Sph.: Spherical, Cub.: Cubic*

Table 2. Reactive powder concrete mix

Cement kg/m3	Sand kg/m3	Silica Fume % of cement weight	W/C	Super plasticizer % of Cementitious Materials (Cement+Silica)	Steel Fibers % of Total Volume
1000	1000	8	0.25	6	1

Two dial gages of (0.01mm) sensitivity are used. One dial gauge is placed in the center of the bottom face of each specimen to measure the central deflection at the midpoint of shell, and the other is placed on the side face of the edge beam to measure the slip deflection, as shown in the Fig. 2.

The concrete strain has been measured using electrical micro strain. Each specimen has two strain gauges, the position of the first gauge is on the compression face (top surface) at the one third of the distance of the half shell measured from the shell end and the position of the second is on the tension face (bottom surface) at the center of the shell as shown in the Fig. 3.

The test of the shell specimens carried out in the construction laboratory in the faculty of engineering of the Mustansiriyah university.

Figure 2. Deflection measurement

Figure 3. Strain measurement.

4. Results and Discussions

Table 3 shows the load and deflection values in the first and ultimate loading stages. In general, the relationship between the load and deflection is an extrusive relation and also whatever the voids are found, the deflection increases and the carrying load capacity decreases. The results are summarized in the following points:

Table 3. First and ultimate cracking loads and deflection

Shell Coding	First Cracking Load (Pcr) kN	Deflection at Cracking Load (Δcr) mm	Ultimate Load (Pcr) kN	Deflection at Ultimate Load (Δu) mm
S-B	27.5	6.4	57.5	13.7
V-Uni-Cir-B	12.5	2.41	37.5	17.8
V-Uni-Cir-TB	17.5	1.98	42.5	15.2
V-Uni-Squ-B	15	3.03	40	14.67
V-Uni-Squ-TB	20	4.44	45	14
V-Bia-Sph-B	12.5	1.8	47.5	13.96
V-Bia-Cub-B	20	3.1	52.5	13.5

1. The voided cylindrical shell (V-Uni-Cir-B) has the least value of ultimate load (37.5 kN) and the solid cylindrical shell (V-Bia-Cub-B) has the least value of deflection in comparison with the other cylindrical shell (Uniaxial and Biaxial). The absence of the voids in the cylindrical shell would increase the stiffness and the first crack and ultimate loading. Fig. 4 shows the load deflection curves of the seven specimens.

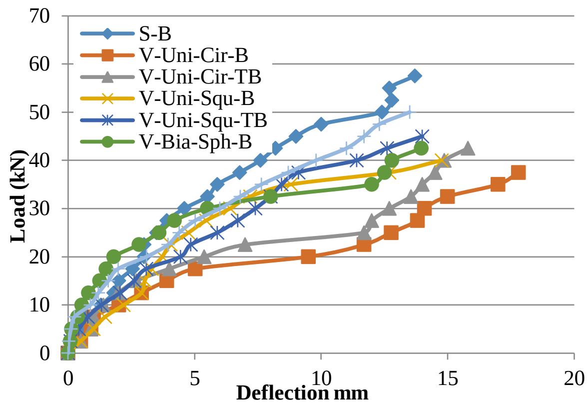

Figure 4. Load - mid span deflection curves of all specimens

2. The results show that the square void in the uniaxial direction as a continuous void (V-Uni-Squ-B) improve the structural behavior by increasing the carrying load capacity and decreasing the deflection more than the circular continuous void (V-Uni-Cir-B) as shown in the Fig. 5.

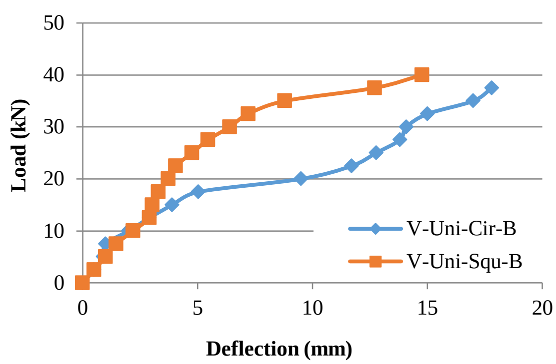

Figure 5. Load - mid span deflection curves of specimens with uniaxial voids.

3. The carrying load capacity of the cylindrical shell with cubic voids in the biaxial direction (V-Bia-Cub-B) increases by (9.5%) and the deflection decreases by (3.3%) compared with (V-Bia-Sph-B) as shown in the Fig. 6. It seems that the cubic or square void shape with straight edges exhibits a better stress distribution than the circular or spherical shape with curve lines.

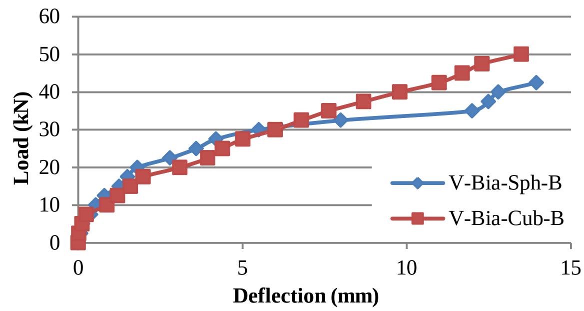

Figure 6. Load - mid span deflection curves of specimens with biaxial voids.

4. The load capacity for the shell (V-Bia-Sph-B) increases by (21.1%) and the deflection decreases by (21.6%) compared to the shell (V-Uni-Cir-B) at the same stage of loading. As well as, the load capacity increases and the deflection decreases by (23.8%) and (8%) respectively, for the shell (V-Bia-Cub-B) compared to the shell (V-Uni-Squ-B) as shown in the Fig. 7. The interpretation of the increasing the load capacity and decreasing the deflection is due to the increasing of the volume of concrete by (25%) in the cylindrical shells with voids in the biaxial direction with separated cubic or spherical voids in comparison with uniaxial direction with continuous circular or square voids.

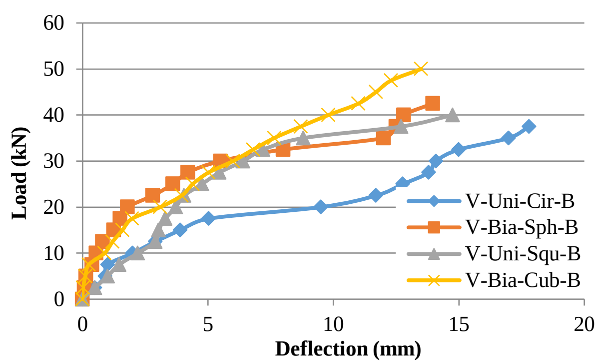

Figure 7. Load - mid span deflection curves of specimens with biaxial and uniaxial voids

5. The effect of additional top steel reinforcement mesh for the shell (V-Uni-Cir-TB) leads to increase the load capacity by (11.8%) and to decrease the deflection by (14.6%) compared to the shell (V-Uni-Cir-B) at the same stage of loading. As well as, the load capacity of the shell (V-Uni-Squ-TB) increases by (11.1%) and the deflection decreases by (4.6%) compared to the shell (V-Uni-Squ-B). The reduction in the deflection values for shells (V-Uni-Cir-TB and V-Uni-Squ-TB) attributed to that the top reinforcement increases the flexural strength and load capacity of the section, this lead to a significant effect on the first and ultimate loading cracks with increasing loading stages.
6. The compressive and tensile strains increase with the reduction of the total concrete volume of the specimen. The strains of the uniaxial (hollow) specimens are more than the strains of the biaxial (bubbled) specimens which are in turn more than the strains of the solid cylindrical shell specimens. The increasing of strains is attributed to that the

continuous void (circular pipes or square cork blocks) occupying space from the total volume larger than the biaxial and solid cylindrical shell. Also, the voids are positioned in the middle of the cross section, where concrete has limited effect, and this leads to a significant increase in the concrete strains. The lesser amount of concrete used in uniaxial cylindrical shell leads to decrease the stiffness and increase the compression and tension strains.

7. For the biaxial cylindrical shell, the compression and tension strain values mediates between solid and uniaxial cylindrical shell. This attributed to a large amount of concrete in biaxial cylindrical shell than the uniaxial cylindrical shell roof and less than the solid cylindrical shell. The solid cylindrical shell has the least value of compressive and tensile strains and this because the absence of voids which means that the stiffness of solid cylindrical shell would be high that leads to decrease the strain. Fig. 8 and Fig. 9 show the stress strain relationships of all cylindrical shells in the tension and compression faces respectively.

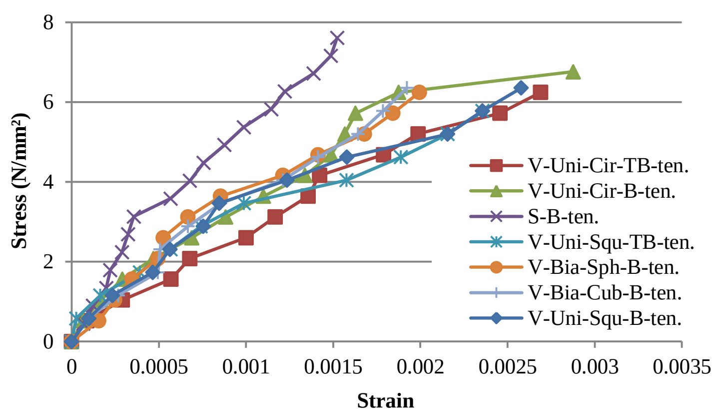

Figure 8. Stress-strain relationships (tension)

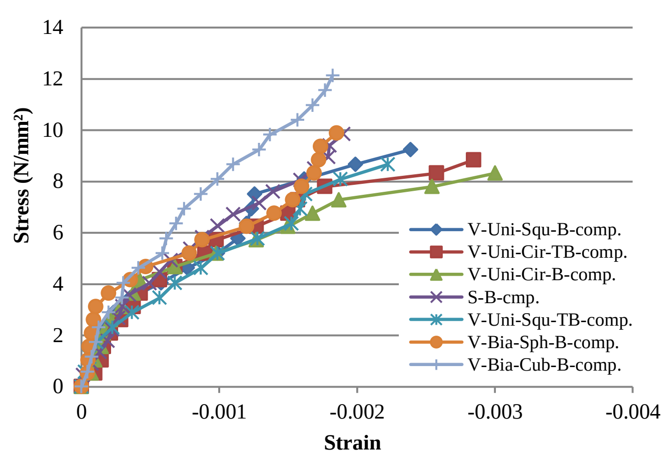

Figure 9. Stress-strain relationships (compression).

8. The compressive and tensile strains are increased by using bottom reinforcement only as in the voided cylindrical shell (V-Uni-Cir-B) and (V-Uni-Squ-B) in comparison with the voided cylindrical shell (V-Uni-Cir-TB) and (V-Uni-Squ-TB). The flexural strength of the voided section increases by using double reinforcement layers which leads to decreasing the flexural strain values.
9. The cracks seem at the bottom surface of the concrete cylindrical shell in the mid span and increased upwards through the loading stages. Through increasing applied load, the displacement of cylindrical shell begins to increase at a higher degree as more loads are applied and the ultimate crack occurs in the bottom face along the width of shell. The ultimate failure crack and flexural failure modes in the cylindrical shell are shown in Fig. 10 and Fig. 11.

Figure 10. Crack Patterns of (V-Uni-Cir-TB)

Figure 11. Crack Patterns of (V-Uni-Squ-B)

5. Conclusions

The following conclusions depending on the experimental results have been reached.

1. The use of the continuous uniaxial and biaxial voids in the cylindrical shells saves the concrete consumption by 32% and 15% respectively compared to solid cylindrical shell.

2. The total volume of the shells with biaxial voids is more than the total volume of the shells with uniaxial voids by (25%). Thus, the load capacity increases and the deflection decreases for the cylindrical shells with biaxial voids (V-Bia-Cub-B) and (V-Bia-Sph-B) in comparison cylindrical shells with uniaxial voids (V-Uni-Squ-B) and (V-Uni-Cir-B).
3. The carrying load capacity of the solid cylindrical shell (S-B) increase by (26.1%, 30.4%, 17.4%, 9%), while the deflection decrease by (23%, 7%, 2%, 1.5%) in comparison with (V-Uni-Cir-B, V-Uni-Squ-B, V-Bia-Sph-B, V-Bia-Cub-B) respectively.
4. The load capacity of the voided shell with uniaxial squared voids (V-Uni-Squ-B) and (V-Uni-Squ-TB) increases by (6.25% and 17.6%) and the deflection decreases by (5.6% and 7.9%) respectively in comparison with voided shell with uniaxial circular voids (V-Uni-Cir-B) and (V-Uni-Cir-TB).
5. The carrying load capacity increases and the deflection decreases for the shell with biaxial cubic voids (V-Bia-Cub-B) by (9.5% and 3.3%) respectively in comparison with biaxial spherical voids (V-Bia-Sph-B).
6. Beside the voided cylindrical shells satisfy the green buildings and sustainability requirements, these structures are more aesthetic and have the enough strength to resist the external loads in spite of strength reduction due to the internal voids. The results showed that the voided cylindrical shell segments are stable and have enough strength under service loads.

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6. References

1. Donnell, L.H., 1976, "*Beams, Plates and Shells"*, New York: McGraw-Hill, Inc.
2. Hauso, A., 2014, "*Analysis Methods for Thin Concrete Shells of Revolution*", M.Sc. Thesis, Norwegian University of Science and Technology, pp. 1 – 3.
3. Dirk, W., Jianxin, Ma., 2003, "*Mechanical Properties of Ultra High Strength Concrete"*, Institute for Massivbau and Baustoffechnologic, University of Leipzig, LACER No. 8, pp 175-184.
4. ACI Committee 318, 2011, "*Building Code and Commentary (ACI 318M- 11)*", American Concrete Institute.
5. Dirk, W., Jianxin, Ma., 2003, "*Mechanical Properties of Ultra High Strength Concrete*", Institute for Massivbau and Baustoffechnologic, University of Leipzig, LACER No. 8, pp 175-184.
6. Marais, C., 2009, "*Design Adjustment Factors and the Economical Applications of Concrete Flat-Slabs with Internal Spherical Voids in South Africa*", M.Sc. Thesis, University of Pretoria, August.

7. Alfeehan, A. A., Abdulkareem, H. I., and Mutashar, Sh. H., 2017, "*Flexural Behavior of Sustainable Reactive Powder Concrete Bubbled Slab Flooring Elements*", Challenge Journal of Structurual Mechanics, Vol. 3, No. 2, pp 81-89.
8. Fischer, N. Test Report, 2008, "*Fixing Tests for Bubble Deck*", United Kingdom, www.BubbleDeck-UK.com.
9. Pfeffer, K. and Martina, S., 2002, "*Transverse Force Capability of the Bubble Deck*", Technical University Darmstadt's Institute for Solid Construction, Volume 24, Issue 6, Pages 551-556 Germany.
10. Nielsen, M.P., 2006, "*Technical Report AEC Consulting Engineers Ltd*", Tech. Univ. of Denmark.
11. Calin, S. and Asavoaie, C., 2010, "*Experimental Program Regarding Bubble Deck Concrete Slab with Spherical Gaps*", Technical University of Iaşi, Romania, Proceedings of The 8-th International Symposium, Concepts in Civil Engineering, pp. 154-161.
12. Kim, S.H., 2010, "*Flexural Behavior of Void RC and PC Slab with Polystyrene Forms*", Hanbat National University, Korea, Vols. 452- 453, pp. 61-64.
13. Lai, T., 2010, "*Structural Behavior of Bubble Deck Slabs and Their Application to Lightweight Bridge Decks*", M.Sc. Thesis, Massachusetts Institute of Technology.
14. Chung, J.H., Choi, H.K., Lee, S.C. and Choi, C.S., 2011, "*Flexural Capacities of Two-Way Hollow Slab with Donut Type Void*". Proceeding of annual conference of the architectural institute of Korea, pp 9-20.
15. Salman, W. D., 2012, "*Flexural Behavior of Bubbled Reinforced Concrete Slabs*", Ph.D. Thesis, University of Baghdad.
16. Khalaf, S.H., 1998, "*Structural Behavior of Long-Span Ferrocement Roofs*", Ph.D. Thesis, University of Technology, Building and Construction Department, Baghdad.
17. Al-Rifaie, W. N. and Al-Ihmedawi, A.N., 2000, "*Structural Behaviour of Ferrocement Shell Roofs*", Journal of Ferrocement, Vol. 30, No. 1, pp. 85-103.
18. Gao, R., Stroeven, P., and Hendriks, C. F., 2005, "*Mechanical Properties of Reactive Powder Concrete Beams*", ACI Special Publication, Vol. 228, No. 79, pp.1237-1252.
19. Dauriac, C., 1997, "*Special Concrete May Give Steel Stiff Competition*", The Seattle Daily Journal of Commerce, pp5, May 9.
20. Voo, J., Foster, S., and Gilbert, R., 2003, "*Shear Strength of Fiber Reinforced Reactive Powder Concrete Girders without Stirrups*", the University of New South Wales, Sydney 2052 Australia, UNICIV Report No. R-421, pp 131.
21. Orgass, M. and Klug, Y., 2004, "*Steel Fiber Reinforced Ultra High Strength Concretes*", Institute for Structural Concrete and Building Materials, University of Leipzig, Lacer No. 9, p12, 2004.
22. Al-Neaime, SH., 2006, "*Static and Impact Properties of Reactive Powder Concrete*", Ph.D. Thesis, University of Technology, Baghdad, pp.190.