EFFECT BUBBLES ON THE BEHAVIOR OF REINFORCED REACTIVE POWDER CONCRETE DEEP BEAMS

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ABSTRACT

Implementation of bubbles in reinforced reactive powder concrete deep beams due to reduce their weight are one of the practical solutions. These bubbles could reduce the beams ultimate strength and increase the mid-span deflection. An experimental work was carried out to test the effect of bubbles on the behavior of reactive powder concrete deep beams. Six simply supported deep beam had the same rectangular cross-section, flexural and shear reinforcement. They were cast with overall height (h) of 340 mm, width (b) of 120 mm and they were classified in to two major groups (A and B) because of their total length (L) of (1000 mm and 1400 mm) respectively. The main parameter in this study were existing bubbles, flexural behavior and shear span to depth ratio. The results showed that increasing layer of bubbles caused a decreasing in first load cracking and ultimate loads and increasing in mid span deflection for all beams. Also, the result showed the existence of bubbles was caused reducing the weight of deep beam and ultimate load. For deep beam with shear span to depth ratio (1.11) and with one and two layers the reduction in weight was (9.35% and 18.7%) respectively, while in other hand, there were reduction in ultimate load with (7.31% and 11.7%) respectively. Moreover, the reduction in weight of deep beam with shear span to depth ratio (1.67) and with one and two layers were (13.09% and 26.18%) respectively resulting reduction in ultimate load (12.5% and 21.8%) respectively. Therefore, the effect of bubbles for deep beam with shear span to depth ratio (1.11) more useful than deep beam with shear span to depth ratio (1.67).

Keyword head: Bubbles, Deep beam, Reactive powder concrete, shear span, weight reduction
1. INTRODUCTION

Reinforced concrete deep beam is a common structural member carry heavy loads over short span. There are many useful applications for reinforced concrete deep such as in tall buildings, as transfer girders in offshore structures and in foundations [10]. In some cases, it is desired to have the lower floor without columns therefore the external wall may be designed as deep beams spanning across the column free space [10]. Over the past five decades, extensive laboratory based investigations on the behavior of reinforced concrete deep beams have been carried out. While most of the research concentrated on the shear behavior of normal weight concrete deep beams, the experimental works on the flexural behavior of reactive powder concrete deep beams have also been reported but on a much smaller. In spite of the non-linear distribution of stress and strain across the vertical sections, test results indicate that the flexural strength of deep beams can be predicted with sufficient accuracy by applying the same method used for shallow beams[2,5,9]. There are many factors effecting on behavior of RC reinforced concrete deep beams such as shear span to the effective depth ratio (a/d), clear span to overall depth ratio (Ln/h), properties of concrete and reinforcements, quantity and position of flexural reinforcement and web reinforcement, type and location of loading ; size, shape and location of web openings [3]. In such elements, shear failure is generally control, therefore the shear strength of deep beams is a major attention in their design [11]. However flexural failure can occur due to use insufficient tensile reinforcement or corrosion flexural bars, causing catastrophic failure [6].

For the time being, the most important development in concrete technology has recently succeeded in producing new cement-based materials that have not only high compressive strength but also superior mechanical properties such as: high durability, high ductility, limited shrinkage, high resistance to corrosion and abrasion [7,8] so that it has attracted the attention of practitioners and researchers. Reactive powder concrete, which is now more defined as ultra-high performance concrete (UHPC) and these terms may be used interchangeably [4]. RPC consists of large cement quantity, fine sand (particle size less than 600 μm), silica fume, super plasticizers and steel fiber [1]. Steel fibers offer multi-directional reinforcement in concrete, simple detailing without congestion, and enhanced post cracking residual strength and ductility. Because of heavy weight of deep beam due to its large cross-section, therefore it is important to find new techniques or ways to reduce the weight. The plastic bubbles or ellipsoid take place some quantity of the concrete to reduce the self-weight of the structure. The creation of a new hollow beam with plastic balls as hollow bodies has required investigating the structural behavior.

2. THE EXPERIMENTAL PROGRAM

2.1. Materials

The type of cement used in the present study was Ordinary Portland cement (OPC). The fine sand with maximum particle size of 0.6 mm was provided from Al-Ukhaidher Natural Sand Quarry. For RPC mixing, silica fume usually used as a partial replacement of cement (15%). Straight brass steel fibers 0.18 mm diameter and 13 mm long with an aspect ratio of 72 were used throughout the experimental program. A dose of High Range Water Reduction Agent
(HRWRA) is used in this study also (called high performance concrete superplasticizer), equals to 2% litter by the weight of the cement was used in the current study. To constructing reinforcement cage of the specimens, three different sizes of steel bar reinforcement were used. Deformed steel bar with nominal diameter of 12 mm was used as flexural main reinforcing bars in tension, and deformed steel bar with nominal diameter of 8 mm were used in compression zone. While for horizontal and vertical web reinforcement used bars with nominal diameters of 4 mm.

Materials proportions of reactive powder concrete deep beam for one cubic meter of fresh concrete are illustrated in Table 1. The RPC mix design include sand to cement ratio $S/C$ equal to 1.0 and the silica fume content (as partial replacement by weight of cement).

<table>
<thead>
<tr>
<th>Material</th>
<th>Sand</th>
<th>Cement</th>
<th>Silica fume</th>
<th>Steel fiber</th>
<th>SP</th>
<th>w/c ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>1000</td>
<td>850</td>
<td>150</td>
<td>39</td>
<td>2%</td>
<td>22.5%</td>
</tr>
</tbody>
</table>

### 2.2. Test Specimen

Six simply supported deep beams were cast and tested up to failure under symmetrically two top points loading. All beams had the same rectangular cross-section, flexural and shear reinforcement. They were cast with overall height ($h$) of 340 mm, width ($b$) of 120 mm and they were classified into two major groups (A and B) because of their total length ($L$) of (1000 mm and 1400 mm) respectively. The longitudinal flexural reinforcement contained of two deformed steel bars with 12 mm nominal diameter and had been checked with Articles 9.9.3.2 and 9.6.1 of the ACI 318 –14 code, the longitudinal compression reinforcement had two deformed steel bars with 8 mm nominal diameter. While the shear reinforcement (reinforcement along the side faces of deep beams distributed perpendicular $A_v$ and parallel $A_{vh}$ to the longitudinal axis of the beam) made by steel distributed at a spacing of 58 mm c/c in both directions with 4 mm diameter. Proposed shear reinforcement aspects had been checked with Articles 9.9.3.1 and 9.9.4.3 of the ACI 318 –14 code.

The plastic bubbles that used in this study with diameters of (90 mm) and fixed in their position by using steel reinforced mesh.

To avoid local crushing of concrete we put steel bearing plates of 140 mm length, 60 mm width and 15 mm thickness. Figure 1 shows the details of the specimens used in this study.
3. NOMENCLATURE

1-S = 1 METER TOTAL LENGTH-SOLID (REFERENCE)

4. TESTING PROCEDURES

All of 6 deep beams were tested in four points bending using the frame and jack testing machine with a capacity of 100ton. A stiff I-section steel was used to support the deep beam. The load test specimens were applied symmetrically using two point loads and the load was applied to the specimen through a rigid I-section steel beam located on the top of the specimen and its reaction against the specimen, the distance between the two point loads was changed according to group of deep beam to give different shear spans.

Deep beams specimens were located inside the testing frame and adjusted so that dial gauges, the centerline of point loading and supports were fixed in their correct places. Then a small pre-load was applied to maintain the positioning. The load was applied with 10kN as increments. At each load increment, the mid-span deflection of the beam was measured, steel strains and concrete strain were measured by data logger. Crack spread was marked and photo at each load increment.
5. THE EXPERIMENTAL RESULT

During the test, the applied load and the vertical mid span deflection, strain of steel and concrete have been recorded at each load step for each tested beam and all cracks which were observed are marked on the beams.

5.1. Effect bubbles

As predictable, the initial stiffness and overall response of the deep beams differ depending on the shear span to depth ratio and existing of bubbles (1 or 2 layers). A clear reduction in the deep beam stiffness occurs with the formation of the first crack at mid-span. Moreover, expected variation in stiffness is detected after yielding of the main bending reinforcement or stirrups.

5.1.1. Load-deflection response and ultimate load

At the beginning before any cracking observes, the load deflection relationship is almost linear and identical for all beams as it depends on the stiffness of the beam. As expected and it could be noticed that mid span deflection is increased as layers of bubbles are increased for the same shear span to depth ratio. Also, the ultimate load is decreased as layers of bubbles are increased. Figure 3 (a,b) and Table 2 illustrate the decreasing of ultimate load of tested deep beams mid – span deflection corresponding to the service load level of deep beams for each group.

![Figure 2 - The testing system](image)

![Figure 3 (a,b) Load-deflection curves](image)
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Table 2: Reduction in ultimate load

<table>
<thead>
<tr>
<th>Group</th>
<th>Specimen</th>
<th>Ultimate load kN</th>
<th>% Reduction in ultimate load</th>
<th>% Reduction in weight (per meter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>1-S</td>
<td>410</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1-1LB</td>
<td>380</td>
<td>7.31</td>
<td>9.35</td>
</tr>
<tr>
<td></td>
<td>1-2LB</td>
<td>362</td>
<td>11.7</td>
<td>18.7</td>
</tr>
<tr>
<td>Group B</td>
<td>1.4-S</td>
<td>320</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1.4-1LB</td>
<td>280</td>
<td>12.5</td>
<td>9.35</td>
</tr>
<tr>
<td></td>
<td>1.4-2LB</td>
<td>250</td>
<td>21.5</td>
<td>18.7</td>
</tr>
</tbody>
</table>

5.1.2. Crack pattern and modes failure

The general behavior of deep beams, the first in the constant bending moment region outside the shear span a few hairline flexural cracks formed. Then, when applied load was increased, the first diagonal cracks began to form at one third-depth near support. Moreover, the flexural cracks were extended to the compression zone of the deep beam until they reached about two-thirds of the whole depth of the deep beam and the diagonal cracks initially extended towards the support and points load and subsequently. The failure modes for all specimens are flexural failure; this failure mode was occurred when the main flexural steel reinforcement reached yielding.

Figure 4: Mode of failure

Figure 5: The first cracks

5.1.3. Strain of steel and concrete

At each loading step, strain in main steel bars and concrete have been recorded by using data logger. These records are based in strain gauges fixed at mid steel bar for main flexural reinforcing and the strain gauge of concrete was fixed on the top surface of mid-span deep beam to detect the strain of concrete at compression zone.
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From Figure 6, it can be notice that the control deep beams (1-S and 1.4-S) failed flexural and the flexural reinforcing reached to yield stress. Also, it can be observed that the existing bubbles causing flexural failure but with increasing yield stress of flexural reinforcement.

As expected and it could be noticed that top concrete strains are increased with presence of bubbles for the same shear span to depth ratio. Also, the top concrete strain was observed a slight increase as layers of bubbles were increased. Figure 7 show the increasing of top concrete of tested deep beams corresponding to the load level of deep beams for each group.

5.2. Effect of shear span to depth ratio
The experimental results show that the shear span to depth ratio is main effectiveness factor and dominate on the behaviour of RPC deep beams.

5.2.1. Load deflection response and ultimate load
Also and as expected the reduction of ultimate load was noticed for higher shear span to depth ratio. Figure 8 show the different in vertical mid span deflection for all beams comparing group A with group B.

The general behavior of deep beams with shear span to depth ratio equal to 1.67, the load-deflection response displays that the stiffness of deep beam decreases after formation the first flexural crack compare with shear span ratio equal to 1.11. The reduction of stiffness reduces with reducing shear span to depth ratio. As predictable, after the formation of the first diagonal crack the deep beam of the same shear span to depth ratio but with one layer bubbles or two layer bubbles was noticed a higher fall in stiffness.
5.2.2. Crack pattern and mode failure

Also, crack patterns and modes of failure are influenced by the shear span to depth ratio. The first flexural crack for controls beam (1-S and 1.4-S) had been observed in load stage (80 and 60 KN) respectively. Also the first diagonal cracks were formed in load stage (110 and 90 KN) respectively. The flexural cracks in deep beam 1-S of (a/d =1.11) to about propagated 61% of the total height of the deep beam whereas for deep beam 1.4-S of (a/d =1.677) the flexural cracks extended to about 82% of the beam height. Whereas the diagonal cracks in beams (a/d =1.11) extended to about 95% of load path and for beams of a/d=1.67 propagated less than 1-S. Also it was observed that the diagonal cracks of 1-S were more inclined compare with 1.4-S when the slope measured with vertical axis and it be noticed that the flexural cracks of 1.4-S were more than 1-S.

5.2.3. Strain of steel and concrete

It was noticed that from the experimental results confirm that the steel and concrete strains deep beams were affected by the shear span to depth ratio. The steel strain and concrete strain at top side face increase with increasing shear span to depth ratio. Figure 9 and Figure 10 shows that the top concrete strain and steel strain increases by increasing shear span to depth ratio.
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**Figure 9** Strain of steel

**Figure 10** Strain of concrete
6. CONCLUSION

The failure of deep beam with minimum reinforcing flexural and shear was flexural failure for deep beam with shear span to depth ratio range (1.11-1.67). Also the behaviour of bubbles deep beam with one or two layers was designed with minimum flexural and shear reinforcing is the same failure for solid deep beam that means the existence of bubbles did not change the mode failure of deep beam.

• The existence of bubbles was caused reducing the weight of deep beam and ultimate load. For deep beam with shear span to depth ratio (1.11) and with one and two layers the reduction in weight was (9.35% and 18.7%) respectively, while in other hand, there were reduction in ultimate load with (7.31% and 11.7%) respectively. Moreover, the reduction in weight of deep beam with shear span to depth ratio (1.67) and with one and two layers were (13.09% and 26.18%) respectively resulting reduction in ultimate load (12.5% and 21.8%) respectively. Therefore, the effect of bubbles for deep beam with shear span to depth ratio (1.11) more useful than deep beam with shear span to depth ratio (1.67).

• The existence of bubbles was caused reduction in mid span deflection. For deep beam with shear span to depth ratio (1.11) and with one and two layers the reduction in mid-span deflection was (7.5 % and 17.6%) respectively. But, the reduction in mid-span deflection of deep beam with shear span to depth ratio (1.67) and with one and two layers were (9% and 12%) respectively. In the same time, these reduction opposite the early forming the flexural cracks. The first flexural cracking loads was formed in (60 kN) for two deep beams with shear span to depth ratio (1.11) and with one and two layers. While for deep beam with shear span to depth ratio (1.67) with one and two layers, the first flexural cracking loads was observed in (50 kN and 40 kN) respectively.

• The flexural reinforcing bars were yielding because of the existence of bubbles. existence one layer of bubble in deep beam with same shear span to depth ratio caused earlier yielding than deep beam with two layers. Also for concrete strain, there was obtained a significant strains in top concrete for deep beam with two layers compare to deep beam with one layer for the same (a/d ) because of the mid span deflection is larger.

REFERENCES


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