Strengthening of reactive powder concrete T-beams with openings

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Abstract. In this research, the response of reactive powder concrete T-beams containing openings is studied. The experimental program involves testing of thirteen simply supported beams. The beams have the same dimensions, flexural and shear reinforcements. In this study, four three parameters have been studied: the shape of an opening (circular and square), a location of openings from the support (Lc/2, Lc/3, and Lc/4), and the internally strengthened around of opening using a deformed steel bar. The experimental results showed that the RPC T-beams with circular openings of diameter (110mm) with different locations (Lc/2, Lc/3, and Lc/4) have a flexural strength less than that solid beam by about (12%, 35% and 41%) respectively. While for the RPC T-beams with square openings of dimension (100mmx100mm) with different locations (Lc/2, Lc/3, and Lc/4), the flexural strength is less than that solid beams by (10%, 41% and 55%) respectively. In addition, it is found that the use of deformed steel bars as internal strengthening for the region around the openings has a significant effect on the overall behavior of beam. Where the ultimate flexural strength of these strengthened beams containing (circular and square) openings with different location increased by (9% to 66%) in comparison with the related un-strengthened beams with same openings. Also, this T-beams with openings showed increasing in deflection about (66.7% - 202%) compared with T-beam without openings at the same load. While for these strengthened T-beams with openings showed a reduction in deflection about (50% - 192%) compared with un-strengthened T-beam with openings.

1. Introduction

It becomes clear, that the reactive powder concrete efficiency is an effective materials in building and construction works due to the advantages of the high carrying capacity loading compared to the weight, and homogeneous properties, if they are compared with other building materials. The large advantages of reactive powder concrete related to its high compressive and tensile strength especially in thin section lead to think of using it in high buildings. The openings are carried out in the concrete beams for various of service and investment purposes, such as the rolling of the heating pipes and the sanitary equipment in the residential buildings. There are different shapes of openings design as there is no standard for determining and selecting the shape of the optimal openings. But the designer usually prefers to resort the regular shapes such as circular, square and rectangular openings. The presence of openings has a negative effect on the concrete beams and this effect is manifested in several aspects. The most important of these is the reduction of the maximum load capacity, the change of the distribution of stresses around the opening and the body. In general, the changing in the behavior of beam from simple behavior to complex behavior.
2. Aims of the study

[1] Study the flexural and shear behavior of RP reinforced concrete T-beams contain opening. The parametric study includes (Shape and location) of openings. The opening shapes includes square and circular openings, while the location of openings from the support are (Lc/2, Lc/3, and Lc/4). The behavior of these beams is determined in terms of ultimate failure load, maximum deflection and failure mode.

[2] Study the efficiency of strengthening of RP T-beams contain large openings using internal strengthening with a new method proposed by authors using of deformed reinforcement steel around the openings.

3. Experimental programs

3.1 Cement
The cement used in the mix is called "Ordinary Portland cement" (type1). The chemical composition and physical properties of this type of cement are conforming to the Iraqi specification No.5/1984[8].

3.2 Fine Aggregate (quartz sand)
The sand used in the mix is called (Quartz sand) with maximum particle size 0.6mm with fineness modulus (F.M=3.12) which is a standard and used for produced reactive powder concrete. This type of sand is produced by CONMIX Company in U.A.E. The grading of used this type of sand is stratify to the Iraqi specification No.45/1984[9] (Zone 2).

3.3 Silica Fume
Silica fume is a highly active pozzolanic material and is made as a by-product from the manufacture of Silicon or Ferro-silicon metal from CONMIX company. The mineral admixture added to the mixtures of the research as a partial replacement by weight of cement. The chemical composition and physical properties of silica fume stratify to requirements of ASTM C1240-04[10].

3.4 Superplasticizer (S.P.)
The superplasticizer used in this work is commercially called MegaFlow110, the properties of the superplasticizer conform to requirements of with ASTM C494 Type A and F.

3.5 Mixing water
Through this work, Tab water was used for mixing and curing all the concrete specimens in this work.

3.6 Steel Reinforcement
Deformed steel bars of nominal diameter (ϕ8mm) with 680MPayield stress were used as beams main reinforcing bars in tension face, while (ϕ6mm) deformed steel bars with 672 MPa yield stress were used as stirrups, compression reinforcement and transverse reinforcement of flange stratify to requirements of ASTM A615M-05a.

3.7 Epoxy adhesive
Sikadur®-330 is recommended by CFRP manufacturer to bond CFRP to the concrete. The mixing ratio of the epoxy was four parts resin of component A (white paste) to one-part hardener component B (grey paste) by weight.

4. Reactive Powder Concrete mixes
"Reactive powder concrete" mixes consist of cement, fine sand (quartz sand); silica fume, superplasticizers, and water was used to cast RPC T-beams. The steel fibers are not added to the mix used in these research as many previous researches produced RPC without steel fibers. Materials Proportions of the mix are listed in Table 1. Many trail mix proportions are conducted to get the best trail proportion according to its compressive strength.
Table 1.

Mix Proportions.

| Ingredient       | Quartz sand (600 μm) | cementitious cement | Silica fume* | Water ** | SP*** |
|------------------|-----------------------|---------------------|--------------|----------|-------|
| Quantities (kg/m³) | 1000                  | 900                 | 100          | 220      | 18    |

*10% Silica Replacement ratio of cement weight.

**water/cementitious material (w/cm) =0.22.

*** 1.8% of cementitious materials (cement + silica fume) by weight.

5. Beams Details

The tested beams were designed according to ACI318M-14 specification code with suitable dimensions that can be manufactured, handled and tested as easy as possible. The dimensions of the tested beams were 1000mm in overall length, thick of flange 60mm, width of flange 300mm, width of web 100mm and 150mm depth of web. Figure (1) shows the details of the reinforcement tested beams. All beams are simply supported with net span of 900mm tested under the action of two-point. Table 2. presents the details of specimens used in experimental program.

![Figure 1. Details of reinforcement of tested beams](image)

Table 2.

Details of specimens used in experimental program

| Beam number | Beam symbol | Opening location | Opening Shape | Type of strengthening at opening regions |
|-------------|-------------|------------------|---------------|-----------------------------------------|
| 1           | Bsolid      | ------           | Without       | ------                                  |
| 2           | BC-CNS      | Lc/2             | Circular      | Without strengthening                   |
| 3           | BC-BNS      | Lc/3             | Circular      | Without strengthening                   |
| 4           | BC-ANS      | Lc/4             | Circular      | Without strengthening                   |
| 5           | BS-CNS      | Lc/2             | Square        | Without strengthening                   |
| 6           | BS-BNS      | Lc/3             | Square        | Without strengthening                   |
| 7           | BS-ANS      | Lc/4             | Square        | Without strengthening                   |
| 8           | BC-CSS      | Lc/2             | Circular      | Internal deformed steel bars            |
| 9           | BC-BSS      | Lc/3             | Circular      | Internal deformed steel bars            |
| 10          | BC-ASS      | Lc/4             | Circular      | Internal deformed steel bars            |
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Notation *B – Reactive powder concrete Beam
**S- Beam with square opening
***-B- Beam with opening at Lc/3
****-SS- strengthening deformed steel bars
*****Lc – clear span of beam

6. Details of the internal strengthening around opening using deformed steel bars
The method used for the strengthening beams with opening (which suggested by authors) is used a deformed steel reinforcement bars around the opening is Strut and tie method. Generally, the failure around the openings is occurred as a beam failure or as a frame failure. The suggested strengthening of horizontal bars and inclined bars will resist the two types of failure. The details of reinforcement around the opening are shown in Figure (2).

![Figure2. Details of the deformed steel reinforcement around opening.](image)

7. Test Results
Table 3 shows a summary of the main results from the beams tests.

Table 3.
A summary of first crack load, ultimate load and mode of failure.

| Beam No. | Beam symbol | Crack load (kN) | Ultimate load (kN) | P_cr/P_u | Decrease in strength (%) | Gain in strength (%) | Crack and failure mode |
|----------|-------------|-----------------|--------------------|----------|--------------------------|---------------------|-----------------------|
| 1        | B-solid     | 67.92           | 195.6              | 0.347    | ---                      | ---                 | Tension Cracks (Flexural Failure) |
| 2        | BC-CNS      | 47              | 171.2              | 0.303    | 12                       | ---                 | Flexural Cracks (Flexural Failure) |
| 3        | BC-BNS      | 44.1            | 127.4              | 0.346    | 35                       | ---                 | Shear Cracks (Shear Failure) |
| 4        | BC-ANS      | 37.4            | 115.5              | 0.323    | 41                       | ---                 | Shear Cracks (Shear Failure) |
| 5        | BS-CNS      | 49              | 176.3              | 0.326    | 10                       | ---                 | Flexural Cracks (Flexural Failure) |
| 6        | BS-BNS      | 39.4            | 115                | 0.343    | 41                       | ---                 | Shear Cracks (Shear Failure) |
In the reinforced reactive powder concrete beam decreases its cracking leading to the collapse of the beam at maximum load of 115.5 kN. Also, the presence of a circular opening expand and spread towards the point of force application with the number of cracks around the opening, and end diagonal shear cracks increased further with the expansion and extension of the cracks below and above the opening due to the concentration of the stresses, at a load of 47.2 kN. As the force increased, the shear cracks began to appear at a load of 67.5 kN. As the applied load increases, the shear cracks appeared in the upper and lower beams of the opening, which led to the collapse of the beam at maximum load of 127.4 kN. Figure (3) shows the load-deflection curve of the control beam.

![Figure 3. Pattern Failure of solid beams.](image)

### 7.1 Control Beams

The first crack in the lower face appeared between the two points loading at a load of 67.5 kN. As the load increased, new vertical cracks appeared. The vertical flexural cracks began to appear at a load of 86.3 kN and spread towards the upper face until the collapse occurred on the flexural at a maximum load of 195.6 kN. Figure (3) shows the load-deflection curve of the control beam.

### 7.2. Beams with circular and square opening in different locations without strengthening

#### 7.2.1. Beams with circular opening diameter 110mm

For the beam with a circular opening in the middle of the span, the first crack appeared at the bottom of the opening due to the concentration of the stresses, at a load of 47 kN. As the force increased, the cracks increased further with the expansion and extension of the cracks below and above the opening and spread towards the upper face until the collapse occurred on the flexural at a maximum load of 171.2 kN. For the beam with a circular opening at Lc/3 measured from the supported to the center of openings, the first crack at the bottom chord of the opening from the close side of the supported due to stress concentration was observed at a load of 44.1 kN. As the applied load increases, the shear cracks expand and spread towards the point of force application with the number of cracks Around the opening, and end diagonal shear cracks appeared in the upper and lower beams of the opening, which led to the collapse of the beam at maximum load of 127.4 kN.

While the beam with a circular opening at Lc/4 measured from the supported to the center of openings, the first crack at the bottom chord of the opening from the close side of the supported due to stress concentration was observed at a load of 37.4 kN. As the applied load increases, the shear cracks expand and spread towards the point of force application with the number of cracks Around the opening, and end diagonal shear cracks appeared in the upper and lower beams of the opening, which led to the collapse of the beam at maximum load of 115.5 kN. Also, the presence of a circular opening in the reinforced reactive powder concrete beam decreases its cracking and ultimate load. The ultimate...
loads of beams with circular openings were reduced by 12 to 41% compared to similar beams without openings, see Figure 4.

**Figure 4. Pattern Failure of RPC T-Beam with Circular Opening**

7.2.2. **Beams With Square Opening Dimensions 100x100 mm**

Beam with square opening at $Lc/2$, the first crack appeared at the corner of the lower left opening due to the concentration of the tensile diagonal stresses at a load value 49 kN. The flexural cracks increased further with the expansion and expansion of the cracks around the upper and lower left corner of the opening. With the increase in the applied load, the flexural cracks expand and spread to the point of application of the right force. The number of cracks increased at the corners of the opening which resulted in the collapse of the beam at a maximum collapse load of 176.3 kN. When Beam with a square opening at $Lc/3$, the first crack was appeared at the corner of the right lower opening near the supported because of stress concentration at load value 39.4 kN. In addition, with the increase in the applied load, the shear cracks expand and spread to the point of application of the right force. As the load increased, the shear cracks widened and spread to the point of application of load. The number of cracks increased at the corners of the opening due to the increasing of tensile diagonal stresses which concentrated at at beam corner. Shear cracks were also observed at the lower of the opening. Finally, new and sudden diagonal cracks appeared in the upper and lower of the chord at maximum collapse reached to 115 kN. While the beam with a square opening at $Lc/4$, the first crack was appeared at the corner of the right lower opening near the supported because of stress concentration at load 39.4 kN. In addition, with the increase in the applied load, the shear cracks expand and spread to the point of application of the right force. As the load increased, the shear cracks widened and spread to the point of application of load. The number of cracks increased at the corners of the opening. Shear cracks were also observed at the lower of the opening. Finally, new and sudden diagonal cracks appeared in the upper and lower of the chord at Maximum collapse reached to 115 kN as shown Figure 5.

**Figure 5. Pattern Failure of RPC T-Beam with Square Opening**
7.3 Beams with Circular and Square Opening with Internally Strengthening by Deformed Steel Bars

In this study, the strut-and-tie is used method to calculate the steel reinforcement around the openings. The test results showed that the providing steel bars around circular openings caused an increase in ultimate load by 23% to 36% compared with the circular openings without strengthened. While providing steel bars around square opening caused an increase in ultimate load by 24% to 66% compared with the square openings without strengthening. It was observed that a number of shear cracks at beams with additional diagonal bars are less in number and width compared with similar beams without diagonal bars. Also, the observed number of flexural cracks for the beams with additional diagonal bars compared with similar beams without diagonal bars. Failed in shear mode in a way approximately similar to beams without strengthened, where the additional diagonal bars increase the beam ultimate load and affect failure mode as shown Figure (6).

![Crack patterns](image1)

![Crack patterns](image2)

Figure 6. Pattern Failure Internal Strengthening of RPC T-Beam Containing Square Opening

7.4. Load –deflection relationships

7.4.1 Effect of Opening Locations and shapes

The load versus mid-span deflection curves for beams with circular and square opening at different locations are offered in Figure7. It can be noticed that introducing openings in the beams causing a reduction in the cracking load, ultimate load, and stiffness of them and this behavior depends on the shape opening and location of the opening of the introduced openings. Strengthening regions around openings can compensate the reduction in the beam, cracking load, ultimate load, and stiffness.
Figure 7. Effect of opening location on the load-deflection relationship for beam with circular and square openings.

It can be seen that the load versus deflection relationship are similar for all beams at early stages of loading until the first cracks occur. After that the deflections for the circular and square openings at mid-span (Lc/2) show greater values than the deflections of circular and square opening at (Lc/3 and Lc/4) for each beam until failure, as the bending moment is increased toward the beam center. It can be noted that the load versus deflection relationship are similar for all beams at early stages of loading until the first cracks occur, after that, the deflections for the circular opening and square opening is slightly different when it located at the flexural zone. When the opening is located in the shear zone, the deflection for square opening is more than deflection of the circular opening at the same load.

7.4.2 Effect of Internal strengthening

The beams with opening have been strengthened internally using deformed steel bars around the openings. was found to be an effective method for preventing premature failure of the beam due to "Vierendeel" truss action. Its observed that the beam behaved this strengthened method, approximately similar to the solid beams behavior but this beams showed more shear cracks Figures 8, 9 and 10. From these figures it can be noticed compares the load-deflection relationship for beams with different variation obtain beams. For all beams exhibited similar behavior is noticed up to first cracks began to appear. The crack load and beam stiffness were slightly higher in the solid beams than a beam with opening strengthened internal deformed steel bars. However, the longitudinal reinforcement the beam with opening yielded at a much earlier stage, which led to a large increase in deflection. Comparing beam with internal strengthening and without strengthening showed the stiffness was significantly higher in the beam with strengthened than in the beam without strengthened.
Figure 8. Effect of internal strengthened around circular and square openings at \((Lc/2)\) on load-deflection curve.

Figure 9. Effect of internal strengthened around circular and square openings \((Lc/3)\) on load deflection curve.

Figure 10. Effect of internal strengthened around circular and square openings \((Lc/4)\) on load deflection curve.
8. Conclusions

1. Presence of circular openings with diameter ratio of 0.52 of the total beam depth in three different openings locations (Lc/2, Lc/3 and Lc/4) reduces the strength capacity of the beams by about (12%, 35% and 41%) respectively, increases beam deflection and initiates intensive cracks around the openings. While presence square opening with height ratio of 0.48 from the total depth in the three locations (Lc/2, Lc/3, and Lc/4) measured from support to opening center caused reduce the strength capacity of the beams by about (10%, 41% and 55%) respectively also, increases beam deflection and introduces initiates cracks around openings.

2. The beam with circular openings have the higher first cracking load, ultimate load carrying capacity comparing with the beam with square opening with the same area, so the best shape of openings in these beams are circular openings.

3. For the beam with the opening, the opening has a higher effect in reducing first cracking load and ultimate load carrying capacity when it is location is closer to the support (or to the shearing zone) comparing with the beam with the opening at the flexural zone, so the best position for the location of the opening in these beams is in mid-span of a beam.

4. Strengthening the RPC T-beams with circular openings by using internal deformed steel bars around opening will increase the ultimate loading capacity by about (13%,31%, and 36%) for opening locations (Lc/2, Lc/3, and Lc/4) respectively, and the same strengthening technique for the RPC T-beams with square openings will increase the ultimate loading capacity by about (9%,42%, and 66%) for opening locations (Lc/2, Lc/3, and Lc/4) respectively.

9. References

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