Flexural Capacity of RC Beams with Opening Strengthened using CFRP Sheet

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Abstract. The use of Carbon Fibre Reinforced Polymer (CFRP) in strengthening has found to be an effective material which comprises of characteristic that comply to the requirement of structural component. CFRP was selected as strengthening material because of the capability to resist the corrosion and could regain the loss capacity due to presence of opening. The opening in structural member was essential in order to provide the route for the utility pipe, air conditioning, water supply and electrical conduit. However, the presence of opening has contributed to the reduction of stiffness, increase of deflection and extension of cracking of the beams. Therefore, this research was conducted to overcome the problem where the flexural capacity and the load deflection behavior of RC beam with opening strengthened by using CFRP sheet was analyzed. A total of five beam have been casted and tested. The specimens consist of beams with different type of opening which are rectangular and circular. The size of all specimen was 200 mm width, 250 mm height and 2000 mm for total length. The size of circular opening was 150 mm in diameter while rectangular opening was 150 x 200 mm. Bi-directional CFRP sheet were applied at the opening area as strengthening material and all beams were tested until failure. All of specimen were produced with the designed using 30 mm concrete cover, 6 mm linking size and 10mm main bar size. The testing of specimens comprises of cube compressive test and four-point load for beam testing in order to determine the flexural strength of RC beam. The result from this research indicated that strengthened beam with circular opening which is SBOC-BI exhibit the highest ultimate load of 71.5 kN with flexural failure as the mode of failure.

1. Introduction
Consideration for mechanical and electrical system in a building was important for providing an efficiency of building services. Hence, providing the opening of beam was an essential factor to accommodate the services which comprise of the various system. Nowadays, the arrangement for installation for utility pipe, air conditioning ducts and water supply system seems not economical since it was hang at the ceiling or bolted at the wall surface [1]. This installation required the additional cover to achieve the aesthetic design which has contribute to increases in construction cost.

On the other hand, Chin et al. [2] mentioned that the presence of opening has contribute to the change in beam behaviour which may resulted in reduction of stiffness, increase of deflection and extension of cracking. These element was affected by the high concentration of load at the opening area. In additional, reduction of cross sectional area due to presence of opening have influence the actual beam capacity. Thus, strengthening at the opening area should be consider in order to re-gain the losses capacity of beam. The beam with opening could also lead to high in stress which can contribute to the presence of...
transverse crack [3]. In addition, the behavior of beam influenced the classification of opening whether large or small depends on the occurrence of flexural crack.

The diagonal reinforcement ratio was able to enhance the flexural strength at the opening area which can eliminate the premature shear failure [4]. Insufficient of reinforcement and large spacing of stirrup could lead to the decreasing of beam’s serviceability. Other than that, the previous study stated that the amount of concrete thickness at the bottom and top chord of opening area should be considered in order to develop the flexural and shear strength of the beam [5]. Other than that, the depth of opening should not exceed 50% of overall depth for reducing the weakened area that effected from the presence of opening.

Ali et al. [6] stated that strengthening reinforced concrete structure by using conventional method which comprises of externally bonded steel plates or external post tensioning have been conducted over the past decades. However, this method has found to be not efficient because of existence in corrosion due to steel plate installation and contributed to several problem during maintenance process. Hence, application of FRP was found to be effective and able to contribute to reduce the maintenance process. FRP material was widely used because of its characteristics which are ease in installation, flexible and resistance to corrosion [7]. Furthermore, epoxy resin also has the potential for enhancing flexural and compression strength [8]. The epoxy consists of flexible element which can prevent the elongation of CFRP sheet before failure [9].

2. Materials and methods

Five specimens of beam were casted with the total length of 2000 mm which consist of 30 mm concrete cover, 6mm link size and 10 mm of main bar size. The opening size of rectangular and circular opening was 150 x 200 mm and 150 mm in diameter respectively. The area of the opening was around 60% from the total area of the beam. Thus, figure 1 below illustrates the cross section of all specimens with difference type of opening.
2.1. Concrete
All of the specimens were fabricated by using ready mix concrete that obtained from local supplier. The concrete mixture with grade 30 has been used for conducting this research. The vibrator has been used during the compaction process of concrete into formwork which to avoid the presence of honeycomb.

2.2. Carbon Fibre Reinforced Polymer (CFRP)
Sika Wrap® - 160 BI C/15 bi-directional CFRP as shown in figure 2 below were applied for the two strengthened specimens with opening except for the control beam. The CFRP sheets were cut into 300 mm wide × 700 mm length. CFRP was applied at the side and bottom surface of opening area. Firstly, the surface of beam was prepared by using grinder and were cleaned by using brush which to remove the dust. Then, a thin layer of epoxy was applied at the concrete surface followed by installation of CFRP. Lastly, the second layer of epoxy mixture was applied by using roller in order to ensure the proper bonded between CFRP and surface of beam. Figure 3 shows the application of CFRP at the opening area while table 1 shows the properties of CFRP.
Figure 2. Bi-directional CFRP sheet.

Figure 3. Application CFRP sheet.

Table 1. Properties of CFRP sheet (Sika Wrap® - 160 BI C/15).

| Property                  | Value                             |
|---------------------------|-----------------------------------|
| Density                   | 1.75 g/cm³                        |
| Tensile strength          | 3800 N/mm² (nominal)              |
| Tensile E-modulus         | 230000 N/mm² (nominal)            |
| Elongation at break       | 1.5% (nominal)                    |

Table 2. Properties of epoxy (Sikadur-330).

| Property                  | Value                             |
|---------------------------|-----------------------------------|
| Elongation at breaks      | 0.9 %                             |
| Flexural E-modulus        | 3800 N/mm²                        |
| Density                   | 1.3 kg/L ± 0.1 kg/L               |
| Tensile strength          | 30 N/mm²                          |

2.3. Epoxy
Epoxy were applied at the surface of opening area which is the location of CFRP application. The type of epoxy used was Sikadur 330 and table 2 below shows the properties of Sikadur 330 while figure 4 shows the epoxy used in this research.
Figure 4. Epoxy (Sikadur-330) which consist of Part A and Part B.

2.4. Beam testing

Figure 5 shows the four-point load test which shows the location of point load, supports and LVDT (Linear Variable Differential Transducer). The specimen was placed in the Magnus Frame before the testing process. Forklift and few manpower were needed during the testing process because the length of beam which approaching two meters. Two strain gauges have been installed on the concrete surface at the top of beam while the other two strain gauges were installed at the main reinforcement of the beam prior to concrete casting.

Figure 5. Four-point load test set-up.

3. Results and discussions

3.1. Ultimate load and deflection

Table 3 shows the data of ultimate load and deflection for all five specimens. From the results, it shows that SBOC-BI (strengthened beam with circular opening) exhibit the highest ultimate load with 71.5 kN compared to the other specimen. The application of CFRP as strengthening material for SBOC-BI specimen has contributed to 13.49% of load incremental from SB. Other than that, SBOC-BI also shows the lowest deflection with maximum deflection of 15.005 mm and has proved the effectiveness of CFRP in reducing the deflection. On the other hand, the result of CBOR (beam with rectangular opening) indicated the lowest ultimate load with 58 kN and the highest deflection of 17.235 mm. This revealed that the sharp corner at the opening area was not able to accommodate the concentration of load applied.

Apart from that, SBOR-BI (strengthened beam with rectangular opening) shows the effectiveness of 19.83% CFRP contribution as strengthening material in reducing the deflection behavior of the beam and contribute to the inclination of load compared to CBOR. The load increment for all specimens were
evaluated regarding to SB as the benchmark while the CFRP contribution was the comparison between strengthen and un-strengthened beam for each opening.

Table 3. Experimental results.

| Specimen | Ultimate load (kN) | Load increment (%) | CFRP contribution (%) | Maximum Deflection (mm) |
|----------|--------------------|--------------------|-----------------------|-------------------------|
| SB       | 63                 | -                  | -                     | 16.235                  |
| CBOC     | 63.5               | 1                  | -                     | 16.265                  |
| CBOR     | 58                 | 8                  | -                     | 17.235                  |
| SBOC-BI  | 71.5               | 14                 | 12.60                 | 15.005                  |
| SBOR-BI  | 69.5               | 10                 | 19.83                 | 13.250                  |

3.2. Load-deflection behavior

Figure 6 illustrated the relationship between load and deflection for all specimens. From the graph, it can be seen that all specimen shows the same pattern behavior of load and deflection. It shows that SBOC-BI (strengthened beam with circular opening) indicated the ultimate load of 71.5 kN with 15.005 mm of maximum deflection value while CBOC (unstrengthened beam with circular opening) indicated the ultimate load of 63.5 kN with 16.265 mm of maximum deflection value. The comparison between these specimens revealed that SBOC-BI was able to reach higher ultimate load and lesser deflection value compared to the unstrengthened beam which is CBOC. This proved that the contribution of CFRP as strengthen material has improved the stiffness and load carrying capacity of the beam. The same pattern of the beam behavior also can be seen within CBOR (unstrengthened beam with rectangular opening) and SBOR-BI (strengthened beam with rectangular opening) curve in figure 6 where the application of CFRP has also influenced in improving the stiffness of the beam.

From figure 6, it shows that the curve of CBOC was close to the curve of SB (control beam). Although there was a small differences of ultimate load value between these two (CBOC and SB) specimens, CBOC has indicated the higher deflection value compared to the SB. This is due to the presence of the circular opening at the mid span which has reduced the actual capacity of the beam. CBOR shows the lowest load carrying capacity with the highest deflection value compared to the other specimens due to the stress concentration at the four edges of rectangular opening. It also shows that the presence of CFRP at the opening was able to improve the stiffness and reduced the deflection of the beam.

![Figure 6. Load-deflection behaviour.](image-url)
3.3. Crack pattern and modes of failure

Figure 7(a) shows the illustration of crack pattern while figure 7(b) shows the real cracking pattern of SB. It was observed that the first flexural crack was occurred at the mid span when the load reached 30 kN. As the load applied increased, the flexural crack occurred at the soffit of the beam and propagated to top of beam in vertical direction. From the observation, the width of flexural cracking at the mid span were widen before the failure which lead to the concrete crushing at the compression area of the beam. The beam failed at ultimate load of 63 kN and it can be seen that the modes of failure of SB was in flexural.

![Figure 7. Illustration and real cracking pattern of beam SB.](image)

On the other hand, figure 8 (a) shows the illustration of cracking pattern of CBOR while figure 8 (b) shows the real cracking pattern of CBOR. The first crack line that observed was appeared at the bottom chord of opening when the load exhibit 17.5 kN. When the load increased to 33.5 kN, a crack was occurred and extended to the left bottom corner of opening area. Meanwhile, the presence of the flexural crack was observed at the right bottom corner of opening area and a diagonal crack was existed afterwards when the load reach at 52 kN. The flexural crack along the bottom chord of opening became wider before the beam fail in flexural mode.

![Figure 8. Illustration and real cracking pattern of beam CBOR.](image)

Figure 9 (a) shows the crack pattern of beam SBOR-BI. From the observation, the initial crack was existed when the load approach to 41 kN. It was due to the application of CFRP at the opening which has influenced the initial value of cracking compared to the CBOR that indicated the value of 17.5 kN.
The increases of applied load has propagated the crack to the adjacent of point load location. In the same time, a flexural cracking was occurred at the left side near the opening area when the load reach to 51 kN. The beam failed when it exhibits the ultimate load of 69.5 kN. Figure 9 (b) shows that the flexural failure of the beam.

![Figure 9](image9a.png)  
(a)  
![Figure 9](image9b.png)  
(b)  
**Figure 9.** Illustration and real cracking pattern of beam SBOR-BI.

Figure 10 (a) shows the illustration of cracking pattern of CBOC while figure 10 (b) shows the real cracking pattern and failure mode of CBOC. Through the observation, the initial cracking occurred from the bottom of specimen which was incline to top when the load applied approached 44 kN. At the same time, another presence of flexural cracking has been observed to occur at the bottom chord of the opening which located at the mid span of specimen. When the load applied increased, the flexural cracking also existed at the top chord of the opening while another diagonal cracking occurred at the right side of opening with the same load approach. The cracking width at the mid of span were widen before the beam failure and the beam failed when the load reach 63.5 kN. From the observation, the beam fails in flexural mode.

![Figure 10](image10a.png)  
(a)  
![Figure 10](image10b.png)  
(b)  
**Figure 10.** Illustration and real cracking pattern of beam CBOC.

Figure 11(a) shows the illustration of cracking pattern of SBOC-BI while figure 11 (b) shows the real cracking pattern and failure mode of SBOC-BI. The first flexural crack has been observed at the right side near the opening when the load reach at 35 kN. A diagonal cracking was presence when the load applied increased to 42.5. On the other hand, there were two diagonal cracking was observed which located at the right and left side of the opening when the load exhibit to 44 kN. The crack at the point
load applied enlarged when the load increase to 55 kN. Lastly, the beam fails in flexural mode when the load approached 71.5 kN.

![Cracking Pattern](image1.png)

**Figure 11.** Illustration and real cracking pattern of beam SBOC-BI.

### 4. Conclusions

Through this research, all of five specimens were produced and successfully tested under four-point load testing. The result of all specimens have been analyzed in order to fulfill the objectives of this research. The application of CFRP as strengthening material were applied to each type of opening to evaluate the capacity and behavior of the strengthening specimen. The specimens without strengthening were considered as control specimen and solid beam was the benchmark for all specimens.

In conclusion, SBOC-BI has achieved the highest ultimate load among of all specimen. This is relevant to the expected result of this research which is the beam with circular opening was able to reach the higher load carrying capacity compared to the rectangular opening. SBOC-BI indicated 71.5 kN of ultimate load while SBOR-BI indicated 69.5 kN. This was due to the high stress concentration at the four edges of rectangular opening. From the comparison between control and strengthened specimen of each opening, the ultimate load for strengthened specimens increased due to the presence of the CFRP at the opening. This is followed by the deflection of the beam which has decreased due to the application of CFRP compared to the control beam. From the crack pattern analysis, the crack propagation of control specimen at the opening was extended to the top of specimen which lead to the crushing of concrete. In contrast, the crack pattern of strengthened beam was significantly decreased without presence of concrete crushing. It can be concluded that the application of CFRP as strengthening materials to enhance the flexural capacity for beams with opening as effective and gives promising results. However, more studies are needed to explore the possibilities of different opening location, opening size and opening shapes.

### 5. References

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