© Universiti Tun Hussein Onn Malaysia Publisher's Office

IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Reinforced Concrete Beams with Opening Strengthened using CFRP Sheets

Noorwirdawati Ali[1,2,*], Noor Azlina Abdul Hamid[2], Norhafizah Salleh[2], Siti Radziah Abdullah[1], Zalipah Jamellodin[2]

[1]Repair, Strengthening and Rehabilitation of Structures, Jamilus Research Centre,
Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, MALAYSIA

[2]Advanced Construction Materials, Jamilus Research Centre
Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijie.2019.11.08.030
Received 03 January 2019; Accepted 01 October 2019; Available online 15 December 2019

Abstract: This study explores the behavior of reinforced concrete beam with opening strengthened using CFRP sheets. The beams were deficient in bending and under-reinforced in order for the beams to fail in bending. Load-deflection behavior and strain profile were observed besides the crack pattern and modes of failure. A total of five (5) beams were casted and tested. One (1) beam was treated as control specimen, two (2) beams were reinforced concrete beams with square and circular opening respectively while the other two (2) beams were reinforced concrete beams with square and circular opening strengthened using CFRP sheets. For the strengthened beams, they were wrapped at three sides (U-wrap) of the beams with CFRP sheets. From the experimental results, it is observed that all beams fail in bending as expected. Beam with circular opening (un-strengthened) recorded the lowest ultimate load with 25.7 kN, a decreased for about 6.4% compared to control specimen. On the other hand, beams with circular opening strengthened using CFRP sheets recorded the highest ultimate load of 30.7 kN, which is an increased for about 11.9% compared to control specimen. The conclusion that can be drawn from this study is CFRP sheets can be used to increase the ultimate load of beam with the presence of opening.

Keywords: Reinforced concrete beam, opening, strengthened, CFRP

1. Introduction

Introducing transverse opening to structural members such as RC beam caused sudden changes on cross section of beam and the corners of opening being subjected stress concentration, hence causes transverse cracking around the edges of the opening. Ashour and Rishi (2000) examined the continuous RC deep beams with web opening decreased the load capacity especially opening located nearly to the end supports. The results of testing of high-strength RC deep beams with opening carried by Yang et al. (2006) indicated that concrete strength has a lesser influence on the shear strength when compared to solid beams but diagonal cracks connecting the four-edges of opening to the loading and support points were the lead factor to final shear failure. In addition, repairing such deficient on beam needs to spend a huge amount of labour, time and cost.

There are various types of shapes and sizes of transverse openings in beams. There are different shapes of openings being considered in this experimental study such as rectangular, circular, diamond, trapezoidal, triangular and even irregular shapes (Mansur, 2006). Circular and rectangular openings are the common openings being used even though

*Corresponding author: wirda@uthm.edu.my

there are numerous types of openings. Circular openings are needed to accommodate pipes services like plumbing and electrical supply while rectangular openings often used as air-conditioning ducts in beams. Previous study shows that the edges of a rectangular opening should be rounded off to reduce possible stress concentration at sharp corners, thus improving the beam cracking behaviours in service (Mansur, 2006).

Regarding to the openings size, many researchers define terms of small and large openings in different ways and there is no clear-cut demarcation line to classify whether the opening is small or large. Mansur (2006) considered circular, square, or nearly square in shape as small openings with the condition that the depth or diameter of the opening is in a realistic proportion to the beam size, that is about less than 40% of the overall beam depth.

In order to increase the capacity of beam that is deficient due to opening, strengthening by fiber reinforced polymer (FRP) is one of the popular methods to improve the deficient of RC beam in civil engineering field. Besides FRP, numerous studies have been conducted to improve concrete quality by using various materials such as agricultural waste, construction waste, plastic waste and other recyclable materials (Hadipramana et. al, 2012; Khalid et. al, 2017; Ramzi Hannan et. al, 2017; Jusoh et. al, 2018; Burhanudin et. al, 2018). FRP in civil engineering field can be divided into construction repairs and rehabilitations, and architectural applications. It is widely used in structural design such as beams and columns. It also showed exceptional durability and high resistance to the environmental exposure effects. It is also light and a non-corrosive material. From the study by El Maaddwy & Sherif (2009), carbon fiber reinforced polymer (CFRP) sheets increased strength within the range of 35-73%. A huge number of studies have been conducted on the performance of FRP as strengthening materials. From previous researches, FRP has been seen as a material that gives promising results to improve capacity of beams whether for bending or shear capacity (Lee et. al, 2012; Abdul Samad et. al, 2017; Ali et. al, 2017; Larbi et al, 2012). Therefore, in this study, FRP has been used as strengthening materials to increase beams' capacity that is deficient due to the presence of opening at the mid-span of the beam.

2. Methodology

2.1 Specimen Details

Five reinforced concrete beams were casted in this study. One beam was a control specimen (no opening and not strengthened) while another four beams were casted with circular and square openings. All beams have a cross section of 200 mm width, 250 mm height and an effective length of 1.7 m. The size of square opening is 124 x 124 mm while the diameter of circular opening is 140 mm. All beams were designed to fail in bending. For flexure reinforcement, two reinforcing steel bars of 12 mm high tensile steel were used as a tension reinforcement. The shear reinforcement consists of 6 mm stirrups spaced at 100 mm for the entire span. Fig. 1 to Fig. 5 show the reinforcement details of tested beams and Table 1 shows the summary of specimens. Beam B1 is the control specimen, beam B2 is un-strengthened beam with square opening, beam B3 is un-strengthened beam with circular opening, beam B4 is beam with square opening strengthened using CFRP sheet and beam B5 is beam with circular opening and strengthened using CFRP sheets. Each CFRP sheets applied was in the form of U-wrap which is around the three sides of the beam except the top-side area.

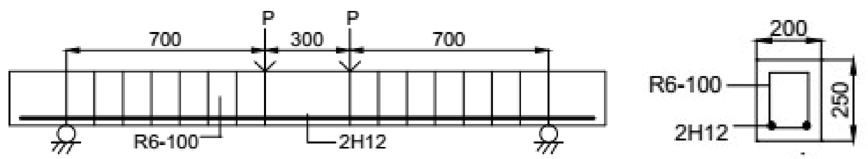

Fig. 1 - Control beam.

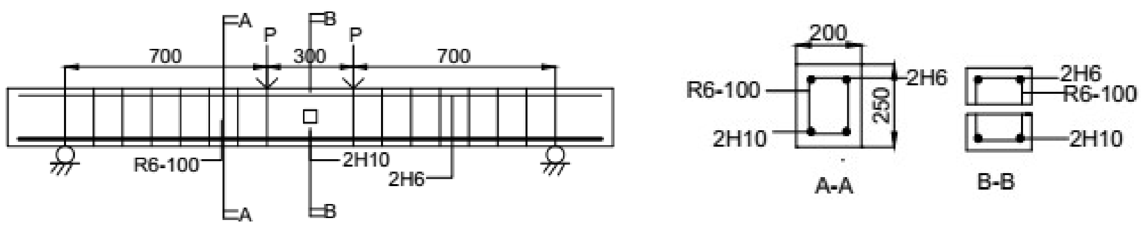

Fig.2 - Beams with square opening.

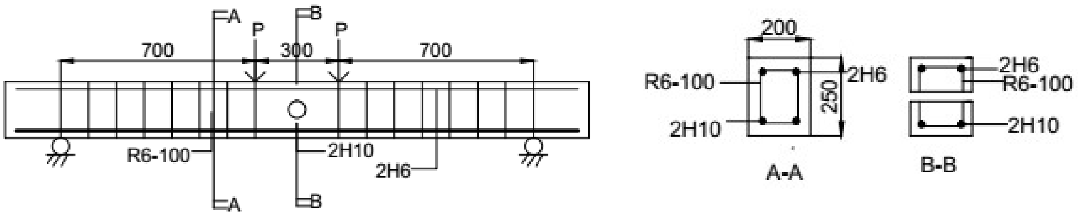

Fig. 3 - Beams with circular opening.

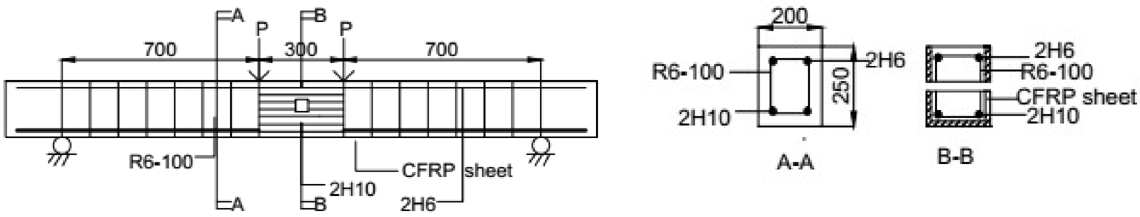

Fig. 4 - Beam with square opening strengthened using CFRP sheet.

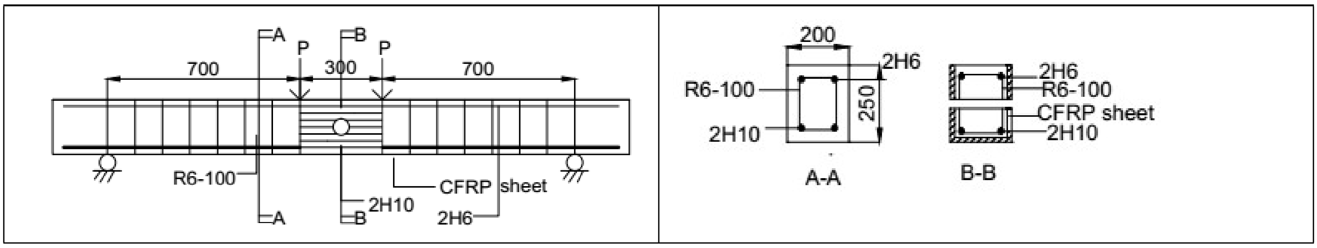

Fig. 5 - Beam with circular opening strengthened using CFRP sheet.

Table 1 - Summary of specimens.

Beam ID	Specification
B1	Control beam (no opening and not strengthened)
B2	Beam with square opening
B3	Beam with circular opening
B4	Beam with square opening strengthened using CFRP sheet
B5	Beam with circular opening strengthened using CFRP sheet

2.2 Material Properties

All specimens were casted using ready mix concrete with compressive strength of 64 N/mm^2. Ready mix concrete was used in order to complete the casting process of all specimens. Nine concrete cubes of 100x100x100 mm were prepared for Compression Test. The cubes were tested on the 7th, 14th and 28th days and Table 2 shows the results of the Compression Test.

The main reinforcement used was high yield steel reinforcement with the diameter of 10 mm whilst for the links, the type of reinforcement used was mild yield steel reinforcement with a diameter of 6 mm. In this research, Sika Wrap-231C (unidirectional fibres), a woven carbon fibre fabric for structural strengthening was used as an external strengthening material. The sheets are available in one roll of 100 m length and 500 mm width and the thickness of the fibre is 0.129 mm. The test for this product was conducted by Road and Bridges Research Institute Poland: IBDiM No AT/2008-03-0336/1. Table 3 shows the material properties of the CFRP sheets based on the manufacturer's manual. Only single layer of CFRP was applied for this experimental work.

Sikadur-330 epoxy system was used as an adhesive in the strengthening system. The consumption of the epoxy was based on the roughness of the concrete beams and skills of the handler. The first layer consumed 0.7 to 1.2 kg/m^2

of Sikadur-330 while the following layers consumed about 0.5 kg/m^2. The properties of Sikadur-330 are shown in Table 4 based on the manufacturer's manual.

Table 2 - Results of compressive strength.

Da ys	Weig ht	Compressive strength	Average compressive
7	2550	44	43
	2530	42	
	2600	44	
1	2575	55	56
	2565	51	
	2580	61	
2	2590	58	64
	2545	67	
	2630	66.2	

Table 3 - Properties of Sika Wrap- 231C.

Fibre orientation	Fabric thickness (mm)	Tensile strength (N/mm^2)	Tensile E-Modulus (N/mm^2)
0º (unidirectional)	0.129	4900	230000

Table 4 - Properties of Sikadur-330.

Density (kg/litre)	Tensile Strength (N/mm^2)	Tensile E- Modulus (N/mm^2)	Elongation at Break (%)
1.30±0.1	30	4500	0.9

2.3 Casting and Curing of Beams

The casting process for all beams was executed in one batch. The concrete was poured in three layers so that the compaction process was executed sufficiently and not overly done. The compaction of concrete was done by using a mechanical vibrator. For curing process, all specimens were covered by plastics as soon as the casting of the specimens completed as shown in Fig 6. Curing process is important in order to make sure the concrete does not lose its moisture or otherwise it could affect the strength of the concrete. After 24 hours, wet sacks were used to replace the plastic. The wet sacks were used until the concrete achieved the age of 28 days and therefore the sacks were poured with water every day in order for the sacks maintain wetted. Fig. 7 shows the specimens after they were detached from the formwork.

Fig. 6 - Curing of the beam after casting.

Fig. 7 - Beams after detached from formwork.

2.4 Testing

All beams were tested at Heavy Structure Engineering Laboratory, Universiti Tun Hussein Onn Malaysia. The effective span of the beams was 1.7 m. The increment of loads was 0.5 kN for each time of adding until failure. The deflection was measured using LVDT and crack pattern was also observed. LVDT were positioned as shown in Fig. 10.

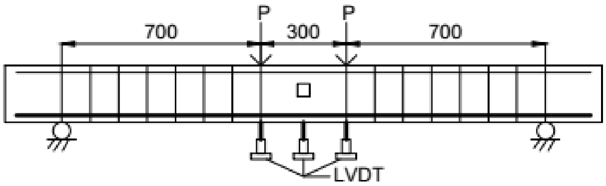

Fig. 10 - Testing set-up

2.5 Strengthening Material Application

For strengthened beams, firstly the locations to apply CFRP sheets were marked. After that, the marked surfaces were grinded by using a mechanical grinder so that the bonding surfaces were rough and clean. Air was then blown to the surfaces to remove any dirt and debris resulted from the grinding process previously. After preparing the concrete surfaces, the epoxy (to bond CFRP to the concrete) was mixed according to the manufacturers' instructions. Four parts of Part A were mixed with one part of Part B (Part A: Part B=4:1). Both parts were prepared separately before being mixed together. The two parts were then mixed together for three minutes until a greyish colour appeared. As soon as the epoxy had been mixed, a thin first layer of epoxy was applied to fill up any holes and uneven surfaces. A second layer of epoxy was then applied before placing the CFRP sheet onto the prepared concrete surface. The CFRP sheet was then rolled to squeeze out the excess epoxy. Fig. 8 shows the beam after CFRP application.

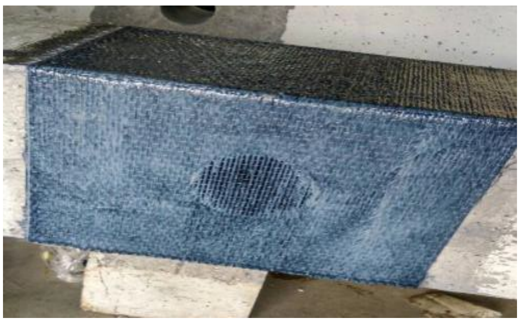

Fig. 8 - Beams after CFRP application.

3. Results and Discussion

3.1 Ultimate Load and Deflection

All beams fails in bending as expected. Table 5 shows the experimental results which comprises of ultimate load, percentage of load enhancement and modes of failure. From Table 5, it can be observed that beam B5 recorded the highest ultimate load while beam B3 recorded the lowest ultimate load. For un-strengthened beams B2 and B3, both beams recorded lower ultimate load compared with control specimen. It can be observed that due to the existence of opening, the capacity of the beam decreased. This is because of the sudden changes in the stress distribution of the concrete. It can also be observed that there is no significant difference between beams with circular or rectangular shape of opening. Both beams recorded lower ultimate load compared to control specimen but the difference of failure load is only around 4%.

Table 5 - Experimental results.

Beam	Ultimate total failure	Percentage of ultimate failure	CFRP contribution in	Mode of
B	27.	-	-	Flexural
B	26.	-	-	Flexural
B	25.	-	-	Flexural
B	28.	4.	7.	Flexural
B5	30.69	11.93	19.60	Flexural

Strengthened beams however, has recorded higher ultimate load compared to control specimen (B1) and un-strengthened beams with opening (B2 and B3). Beam B4 which is a strengthened beam with square opening recorded higher ultimate load compared to beam B2 (un-strengthened beam with opening). It recorded an increase for about 4.6% compared to beam B1 and 7.5% compared to beam B2. For beam with circular opening, beam B5 recorded 11.9% increment of load compared to beam B1 and 19.6% compared to beam B3. This brings a contribution of CFRP for both beam (B4 and B5) for around 7.5% and 19.6%. From the overall experimental result, it can be observed that the existence of CFRP as strengthening materials can improve the capacity of beams with opening.

On the other hand, Table 6 and Fig. 9 shows the deflection value and load-deflection profile of all beams. Beam B2 to B4 recorded lower deflection compared to control specimen beam B1 for around 23.2% to 25.9%. For the strengthened beams, although the two beams recorded higher deflection compared to control specimen, there is no significant different compared to un-strengthened beams with opening (beam B2 and B3). It shows that CFRP is effective in reducing deflection at the same load level. For example from Fig. 12, at the same load level of 25 kN, beam B5 recorded deflection of around 6 mm while beam beam B3 recorded around 15 mm deflection. For beam with square opening, at the same load level of 25 kN, beam B4 recorded deflection of around 4.5 mm while beam B2 recorded deflection of around 12 mm. This shows that CFRP is effective in reducing deflection. The end results of deflection recorded almost similar deflection, however with higher ultimate load for the strengthened beams.

Table 6 - Experimental results.

Beam ID	Ultimate total failure load (kN)	Mid-span deflection (mm)	Percentage of deflection (%)
B1	27.42	22.57	-
B2	26.67	17.30	-23.35
B3	25.66	17.26	-23.53
B4	28.68	16.73	-25.88
B5	30.69	17.25	-23.57

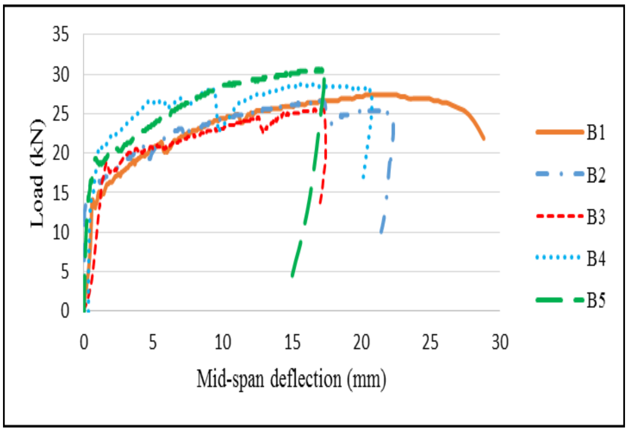

Fig. 9 - Load-deflection profile.

It can also be observed that, from Fig. 9, the load deflection curve showed linear elastic behaviour at the beginning of the testing. However, as the load increased, the curve started to become non-linear due to the development of cracks in the beam. This trend tends to continue with more cracks observed to be occurred until failure of the beams. All beams show almost similar trend as expected for a reinforced concrete beam.

3.2 Crack Pattern and Mode of Failure

Beams were design as simply supported beam where all specimens were loaded equally (two-point load) from the beginning to the failure of the beam. Beams were also design to fail in bending. For better understanding, there are some explanations regarding flexural zone, shear span, flexural crack, compression zone and tension zone. Flexural zone of the beam was located at the mid-span region near the maximum bending moment area. Other than that, tension zone of the beam was located towards the bottom side of beam while compression zone referred to the upper side of the beam. In addition, the term of flexural and shear crack was used. Flexural crack referred to vertical crack while shear crack referred to diagonal crack.

For control beam (Beam B1) which has no opening and not strengthened with CFRP sheets, it was tested and loaded until failure. It was observed that flexural cracks appeared initially at the bottom part of the mid-span. The flexural (or vertical) cracks widened and propagated at the compression zone of the beam as load was increased. The flexural cracks widened and propagated until the beam failed due to bending at a load of 27.42 kN. Fig. 10 shows beam B1 failed in bending. Several vertical cracks were also observed at the shear span. The crack propagation for vertical cracks were similar to the previous researches done by others such as Li et al. (2002) and Jayaprakash et al. (2008). From crack patterns shown in Fig. 11, vertical cracks in the shear zone stopped propagating much earlier than the cracks in the flexural zone. As expected, the beam eventually failed in bending rather than shear as the specimen was designed to fail in bending.

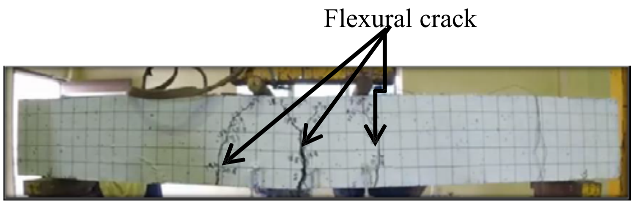

Fig. 10 - Bending failure of beam B1 at load 27.42kN.

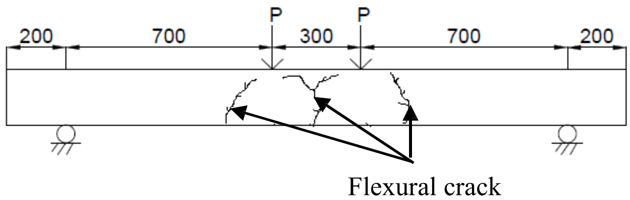

Fig. 11 - Crack pattern of beam B1 (unit in mm).

For un-strengthened beam with square opening (B2), it can be observed that the shear crack appeared initially at the edge of the square opening which was located at the mid-span of beam. This might be due to the square opening that caused the changes in stress distribution and this made cracks easier to happen at the opening area. Moreover, the inclined cracks occurred at the bottom part of square opening, widened and propagated through the opening. Those flexural cracks at the tension zone appeared after cracks formed towards the point loads in the middle region of span and stopped propagating and widening in a very much earlier stage. Most of the cracks were found at the four edges of the square opening as shown in Fig. 12 and Fig. 13. Such cracks lead to beam failure at peak load of 26.67 kN. Hence, beam B2 is more favourable to bending failure than shear failure as expected.

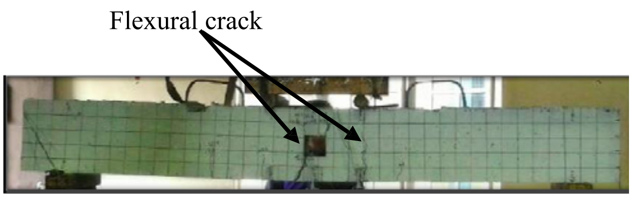

Fig. 12 - Bending failure of beam B2 at load 26.67 kN

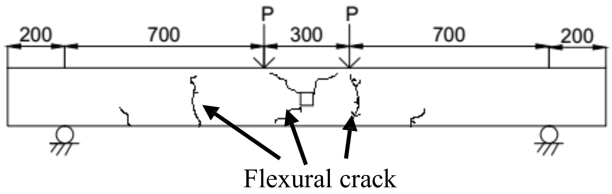

Fig. 13 - Crack pattern of beam B2 (unit in mm).

For beam B3 which is un-strengthened beam with circular opening, its crack initially occurred at the surrounding the circumference of the circular opening located at the span between the two-point load. Flexural crack appeared later at the mid-span near the opening region and it propagated towards the compression zone. Flexural crack happened surrounding the circular opening then widened and propagated in inclined direction as shown in Fig. 14 and Fig. 15. The propagation of flexural cracks at the circular opening, lead to beam failure at the ultimate load of 25.66 kN. Hence, it can be said that this beam leans more towards bending failure rather than shear failure. From the crack pattern propagation, it can be observed that the mode of failure of beam B2 and B3 are almost similar as they were formed at the edges or corners of the opening area.

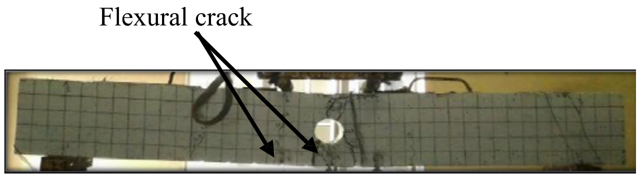

Fig. 14 - Failure of beam B3 at load 25.66kN.

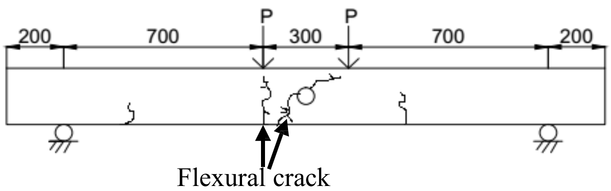

Fig. 15 - Crack pattern of beam B3 (unit in mm).

For Beam B4 with square opening and three sides of the opening area strengthened with CFRP sheets, the first crack started at the area next to the square opening area. The crack then widened and propagated to the point load as shown in Fig. 16 and Fig. 17. It can be observed that there is no crack appeared at the opening area which was strengthened using a CFRP sheet and no rupture of the CFRP sheet either. This showed that the CFRP sheet reduced the crack at the edges of opening area and deformation of beam. Hence, it increased the stiffness and strength of the beam.

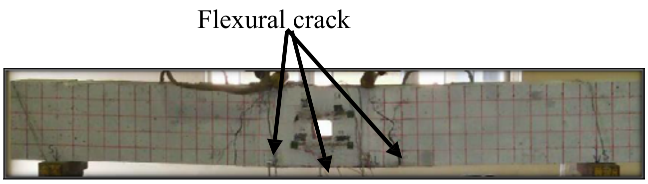

Fig. 16 - Shear failure of beam B4 at load 28.68kN.

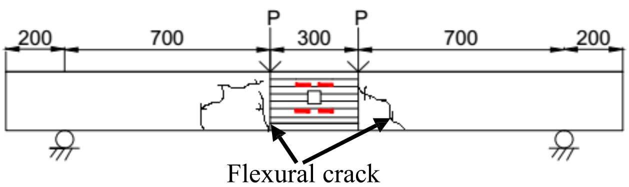

Fig. 17 - Crack pattern of beam B4 (unit in mm).

For CFRP sheets-strengthened beam with circular opening, it can be observed that crack started initially at the tension zone next to the strengthened opening area as shown in Fig. 18 and Fig. 19. The crack then widened and propagated as load increased. The beam is more favourable to fail in bending than shear. There was also no rupture of CFRP sheet at all. Other than that, there was no crack at the opening area and this meant that CFRP sheet contributed to prevent cracking around the opening area.

Based on the data interpretation discussed above, it can be observed that the crack appeared on un-strengthened beam with the square opening was more than those on the beam with circular opening. This is due to circular opening does not contain any edges like square opening. Moreover, the cracks formed on the CFRP strengthened beam with circular opening was lesser than those cracks on the strengthened beam with square opening. This is because of crack more often happened near the sharp edges. Hence, it can be said that CFRP show positive effects to the beam by gaining its strength and reduce cracking and deformation behaviour.

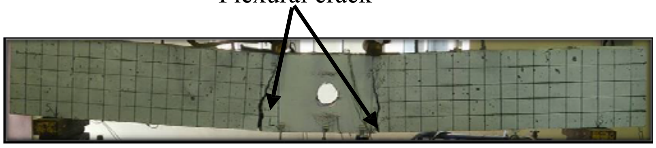

Fig. 18 - Shear failure of Beam 5 at load 30.69kN.

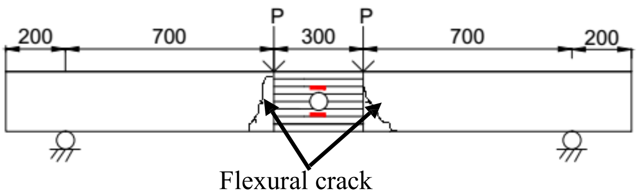

Fig. 19 - Crack pattern of Beam 5 (unit in mm).

4. Conclusions

Based on the obtained results and discussion about the reinforced concrete beams with opening strengthened using CFRP sheets, some conclusion can be drawn as follows:

- The control beam without any opening has the highest ultimate load of 27.42 kN amongst the other two un-strengthened beams with square and circular opening respectively. This shows that the introduction of opening to the beam is more likely to reduce the load-carrying capacity of beam due to the sudden changes of the stress distribution of the stress block diagram.
- Un-strengthened beam with square opening recorded higher ultimate load compared to un-strengthened beam with circular opening.
- Beam with circular opening strengthened with the CFRP sheet recorded the highest ultimate load of 30.69 kN.
- The presence of CFRP sheet as strengthening materials has increased the load carrying capacity of the beam form 7.5% to 19.6%.
- CFRP sheet also contributed in term of deflection and crack behaviour by reducing the deflection in the range of 0.10%-0.30% and also reduce cracking.
- For un-strengthened beam, most of the cracks appeared in between the middle area of the two-point loads (critical region) and some of the cracks widened and propagated towards the direction of point loads.
- For CFRP strengthened beam, the cracks were not formed at the middle region which was wrapped with CFRP sheet but appeared at the shear span or the area next to the middle-wrapped area.
- The un-strengthened and strengthened beams with openings are more favourable to flexural failure than shear failure.

References

[1] Ashour, A. & Rishi, G. (2000). Tests of reinforced concrete continuous deep beams with web openings. ACI Structural Journal, 97(3), 418-426 43-50.

[2] Yang, K., Eun, H. & Chung, H. (2006). The influence of web openings on the structural behaviour of reinforced high-strength concrete deep beams. Engineering Structures, 28(13), 1825-1834.

[3] Mansur, M. (2006). Design of reinforced concrete beams with small openings under combined loading. Proceedings of the 6Th Asia-Pacific Structural Engineering and Construction Conference, 104-120.

[4] Hadipramana, J., Samad, A. A. A., Zaidi, A. M. A., Mohammad, N. & Ali, N. (2012). Influence of polypropylene fiber in strength of foamed concrete. Advanced Materials Research, 488-489, 253-257.
[5] Faisal Sheikh Khalid, Mohd Irwan Juki, Norzila Othman & Mohd Haziman Wan Ibrahim. (2017). Pull-out strength of polyethylene terephthalate bottle fibre in concrete matrix. Malaysian Construction Research Journal, 21(1), 2017, 75-85.
[6] Ramzi Hannan, N. I. R., Shahidan, S., Ali, N. & Maarof, M. Z. (2017). A comprehensive review on the properties of coal bottom ash in concrete as sound absorption material. MATEC Web of Conferences, 103, 01005.
[7] Jusoh, M. A., Abdullah, S. R. & Adnan, S.H. (2018). Strength of mortar containing rubber tire particle. IOP Conference Series: Earth and Environmental Science, 140 (1), 012144.
[8] Burhanudin, M. K., Ibrahim, M. H. W., Sani, M. S. H. M., Juki, M. I., Jamaluddin, N., Jaya, R. P., Shahidan, S., Basirun, N. F. & Bosro, M. Z. M. (2018) Influence of ground coal bottom ash with different grinding time as cement replacement material on the strength of concrete. Malaysian Construction Research Journal, 4, 93–102.
[9] El Maaddawy, T. & Sherif, S. (2009). FRP composites for shear strengthening of reinforced concrete deep beams with openings. Composite Structures, 89(1), 60-69.
[10] Lee, J. Y., Hwang, H. B. & Doh, J. H. (2012). Effective strain of rc beams strengthened in shear with FRP. Composites: Part B, 43, 754-765.
[11] Abdul Samad, A. A., Ali, N., Mohamad, N., Jayaprakash, J., Tee, K. F. & Mendis, P. (2017). Shear strengthening and shear repair of 2-span continuous RC beams with CFRP strips. Journal of Composites for Construction, 21(3), 04016099.
[12] Ali, N., Samad, A. A. A., Jayaprakash, J., Mohamad, N. & Shahidan, S. (2017). Pre-cracked RC continuous beams strengthened in shear using CFRP strips oriented at 45°/135°. Malaysian Construction Research Journal, 20 (3), 5-28.
[13] Larbi, A. S., Agbossou, A., & Hamelin, P. (2012). Experimental and numerical investigations about textile-reinforced concrete and hybrid solutions for repairing and/or strengthening reinforced concrete beams. Composite Structures, 99, 152-162.
[14] Li, A., Diagana, C. & Delmas, Y. (2002). Shear strengthening effect by bonded composite fabrics on RC beams. Composites Part B: Engineering, 33(3), 225-239.
[15] Jayaprakash, J., Abdul Samad, A., Anvar Abbasovich, A. & Abang Ali, A. (2008). Shear capacity of precracked and non-precracked reinforced concrete shear beams with externally bonded bi-directional CFRP strips. Construction and Building Materials, 22(6), 1148-1165.