

Reinforced Concrete Beam with Openings Strengthen Using CFRP Sheet

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Abstract

Reinforced concrete is widely used in numerous parts of buildings, like columns, beams, and slabs. The material contains concrete that provides great compression strength, while steel reinforcement embedded in concrete has great tension strength. The failure of reinforced concrete beams with openings mainly located around the openings. Therefore, strengthening around the opening is required to increase the strength of the beam. In this study, Carbon Fiber Reinforced Polymer (CFRP) sheets are chosen. CFRP are composite materials that consist of carbon fiber with a resin to create material that has higher performance properties compared to each material separated. CFRP sheet provides superiority compared to steel-reinforced concrete that is still used, such as durability and reliability of the materials. This research objected to acknowledging the pattern of failure of reinforced concrete beams using ABAQUS, finite element modeling software in some cases, reinforced concrete beams without any opening, reinforced concrete beams with one circular opening in the shear zone without any strengthening, reinforced concrete beams with two circular openings in the shear zone without any strengthening, reinforced concrete beams with one circular opening strengthened using CFRP sheet, and reinforced concrete beams with two circular openings strengthened using CFRP sheets. Finite Element Method (FEM) are used in this study by ABAQUS software and validate with experimental results. ABAQUS are used to simulate the model using Finite Element Method (FEM). From this study, beam with circular opening strengthened using CFRP have increase of 16.00% and the beam with 2 openings is increasing by 35.00%. The crack pattern of the beam without an opening is concentrated in the mid-span of the beam with a flexural failure, while the other specimen has a shear failure within circular openings. Significant improvements in ultimate load conclude that using CFRP sheet to strengthen beam with circular openings are suitable. The results of load-deflection profile calculated by Finite Element Modeling much higher than experimental results. The differences ultimate load results of Finite Element Method and Experimental are ranged from 2.94% until 9.87%.

1. Introduction

Reinforced concrete is widely used in great number of parts of buildings, like columns, beams, and slabs. The material contains concrete that provides great compression strength, while steel reinforcement embedded in concrete has great tension strength. Reinforced concrete beams with openings increasingly used worldwide to provide utilities and architectural requirements. There are the shapes of the opening, including circular, rectangular, diamond, triangular, trapezoidal, and irregular shapes.

Based on research from Hemzah et al. (2020), reinforced concrete beams with openings reduce the stiffness around the openings, reduce the strength, and may change the pattern of failure of the beam. The failure of reinforced concrete beams with openings mainly located around the openings. Therefore, strengthening around the opening is required to increase the strength of the beam. There are many options can be used to strengthen beams. However, in this study, Carbon Fiber Reinforced Polymer (CFRP) sheets are chosen. CFRP are composite materials that consist of carbon fiber with a resin to create material that has higher performance properties compared to each material separated. CFRP is a type of reinforcement that has several applications in industries, for example, strengthening reinforced concrete structures. CFRP sheet has advantages compared to steel-reinforced concrete that is still used, such as durability and reliability of the materials.

2. Materials and Methods

In this research, 5 beam specimens with various number of openings and CFRP strengthening are provided. All specimens using 150mm width, 300mm depth, and 1900mm length rectangular simply supported reinforced concrete beams with 100mm diameter circular opening. The location of the opening is placed in the middle of shear span. Each beam has two R6 as top reinforcements and three H12 as main reinforcements. As shown in table 1, the first specimen is the control beam which is a normal simply supported beam. The second and the third beams are the beams with 1 opening and 2 openings without CFRP sheet strengthening. The two last beams are the beams with 1 opening and 2 openings with CFRP sheet strengthening. The size of the CFRP sheet is 300x300mm with the hollow at the center of each CFRP sheet and has the same size as beam openings.

Table 1 Specimen Details

Specimen	No. of Opening	Strengthening Material
B-C	-	-
BO-1	1	-
BO-2	2	-
BO-1-SCS	1	CFRP sheet
BO-2-SCS	2	CFRP sheet

2.1 Reinforced Concrete Beam with Openings

Reinforced concrete beam is being used widely for the structure of construction in the entire world. Recently, Reinforced Concrete sections with web openings are frequently used in construction upon the request of the building owners to provide utilities and architectural requirements. The opening part of the beam decreases self-weight and affords an economical design. However, the stress transfer discontinuities in the normal stress flow produced by the openings create high-stress concentration along the opening area that reduces the shear capacity and stiffness of the beam and may lead to premature cracking of the beam surrounding the opening area (Salih et al, 2020; Mwonga et al, 2020).

2.2 CFRP Composites

The shear area, in a reinforced concrete beam, bears both compressive and tensile forces. Many attempts have been made to adapt the concrete material by using high-strength concrete to increase the resistance to compressive forces. However, the ultimate strength is not increased due to tensile stresses. Opening in the shear area makes the tensile stress concentrate around the openings. This causes the beam to early cracking and premature failure. Therefore, the material of concrete can be altered by fibers, which provide high tensile and flexural strength, reduce cracks, and the ductility of beams are improved (Mwonga et al, 2020).

Recently, steel-reinforced concrete is still being used to provide strength and ductility. However, when placed in exposed conditions, steel is sensitive to corrosion caused by oxygen and moisture which makes the quality of the steel decrease and less durable. Therefore, it persevered the researchers to find alternative materials that are

durable. CFRP provides superiority compared to steel-reinforced concrete that is still used, such as durability and reliability of the materials (Tahir et al, 2019).

2.3 Finite Element Analysis (FEA)

Finite Element Analysis (FEA) is a computer-aided numerical method that is used for structural analysis. Finite Element Analysis (FEA) results in Finite Element Modelling (FEM) that could show a material that is loaded and stressed. Finite Element Modelling (FEM) applied points (nodes) and elements that generate a grid called mesh. The mesh acts like a spider web. Each node extends a mesh element to each of the adjacent nodes. This concept aims to calculate an approaching calculation limited to the number of points and interpolate the results for the entire structure (Srireka & Bashetty, 2010).

2.4 Methods

In this study, ABAQUS is used for finite element modeling. Before analyzing, the beams are required to be created. There are steps for set-up the beams shown in Fig. 1 below.

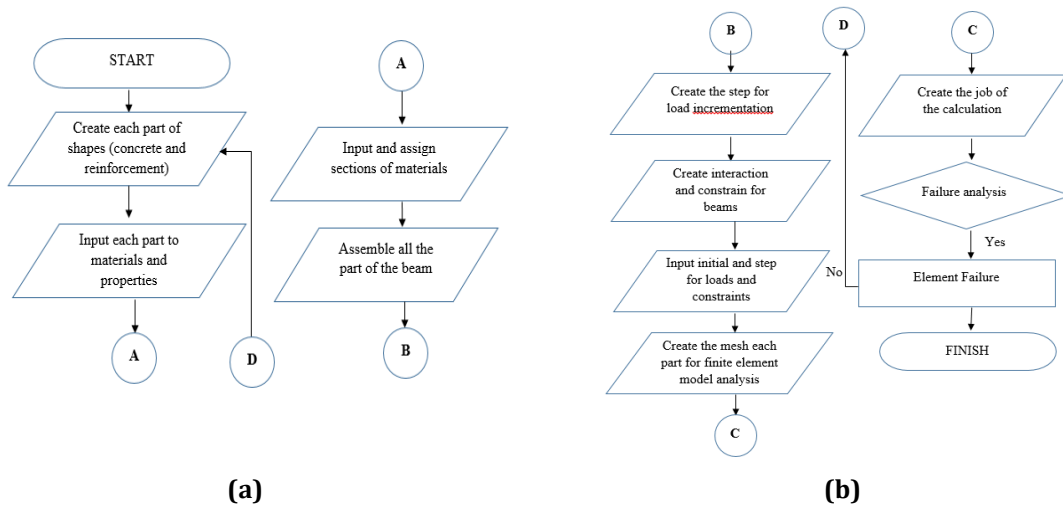


Fig. 1 Analysis Method using ABAQUS (a) Start Process; (b) Continued

3. Results and Discussion

Table 2 Ultimate Load and Deflection Results

Specimen	Pu (kN)				Deflection (mm)	
	FEM	Exp	FEM & Exp % Differences	% Improve	FEM	Exp
B-C	141.6	137.55	2.94	-	2.376	34.25
BO-1	120.0	128.69	6.75	-	2.504	46.95
BO-2	96.0	102.54	6.38	-	2.700	28.85
BO-1-SCS	139.2	134.09	3.81	16.00	2.323	21.9
BO-2-SCS	129.6	117.96	9.87	35.00	2.934	12.5

From data Table 2, we can conclude that adding a circular opening in the beam impacts significantly to ultimate load which has a reduction of 15.25% for 1 circular opening and 32.20%. However, there are increase in ultimate load when CFRP sheets are added around the circular opening. The improvement of ultimate load are 16% for 1 opening and 35% for 2 openings which is close to the control beam value. For deflection, there is great differences both without CFRP and with CFRP due to many factors, for ABAQUS modeling there is not using real crack simulation, while in experimental the specimen fall rapidly after failure. The differences for Finite Element Method and Experimental results for ultimate load are ranged between 2.94% until 9.87%.

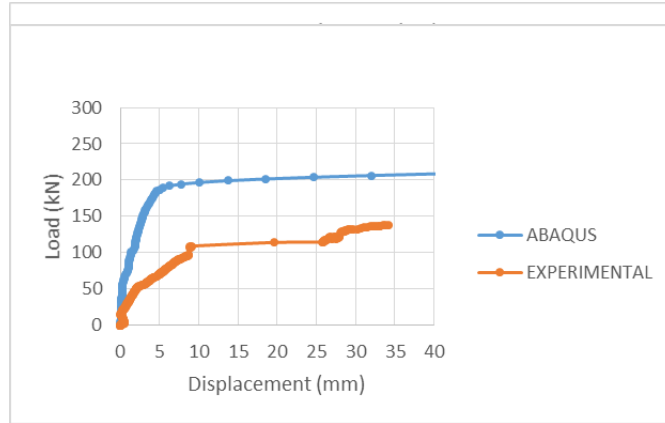


Fig. 2 Control Beam (BC) Load-Deflection Graph

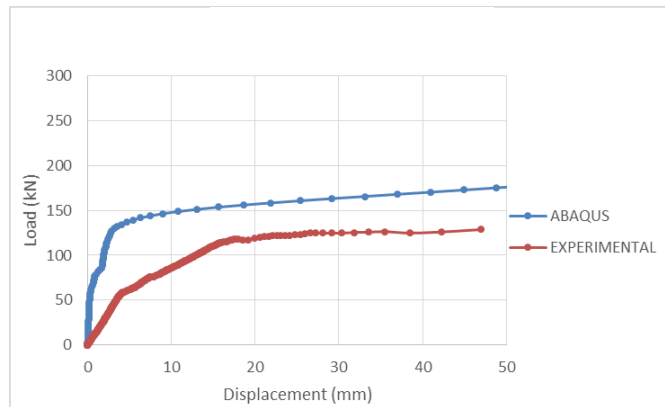


Fig. 3 Beam-1 Opening (B-01) Load-Deflection Graph

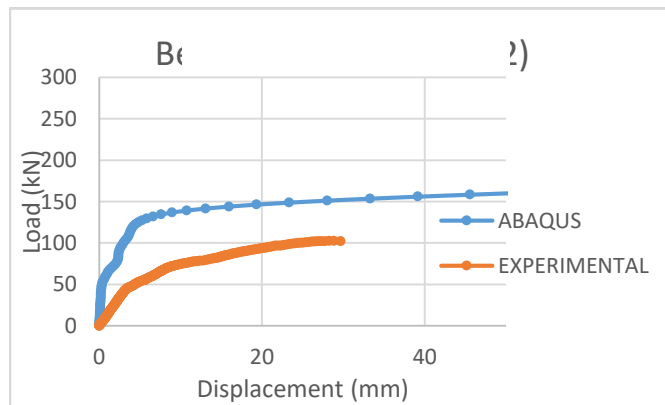


Fig. 4 Beam-2 Openings (B-02) Load-Deflection Graph

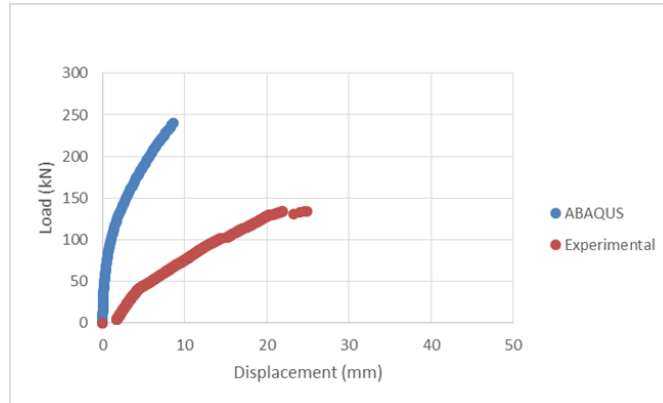


Fig. 5 Beam-1 Opening Strengthened Using CFRP Sheet (B-01-SCS) Load-Deflection Graph

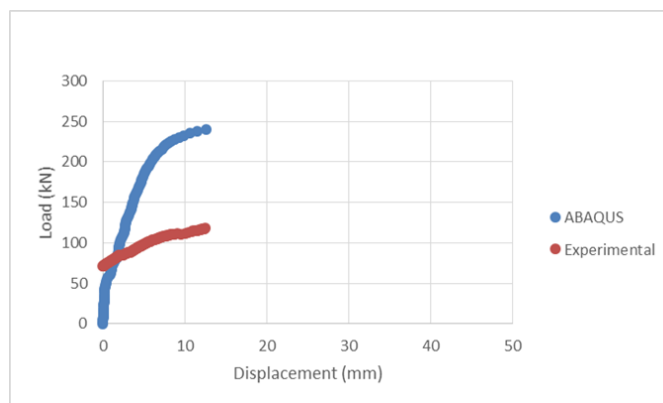


Fig. 6 Beam-2 Openings Strengthened Using CFRP Sheet (B-01-SCS) Load-Deflection Graph

From Fig. 2 until Fig. 6 show that all the specimens have similar behavior. The trend of graphs is positive relationship between load and deflection. The graph shows minor differences when beams are strengthened by CFRP sheets. Beams strengthened using CFRP sheets has a better performed that can be seen from higher first crack load and ultimate load in the graph. The result from ABAQUS is much higher compared to the experimental results.

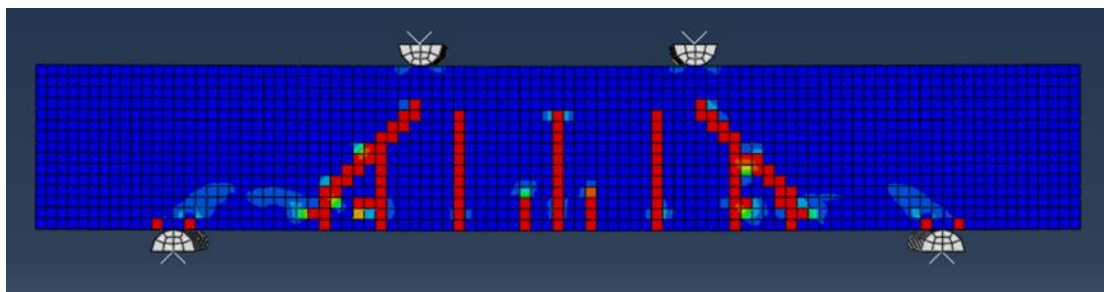


Fig. 7 Control Beam (BC) Crack Pattern

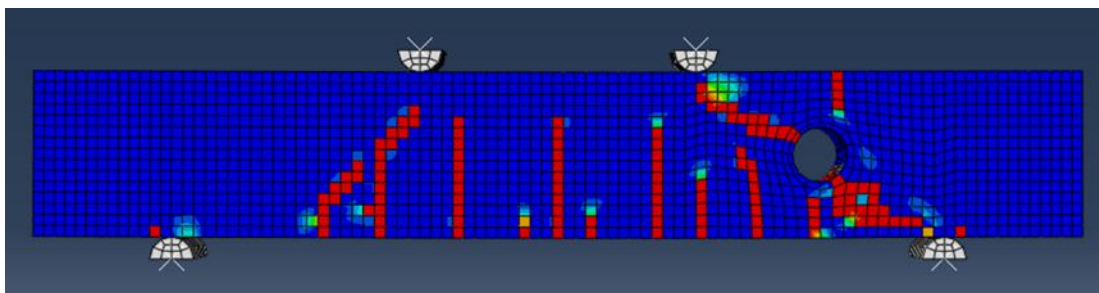


Fig. 8 Beam with 1 Opening (B-01) Crack Pattern

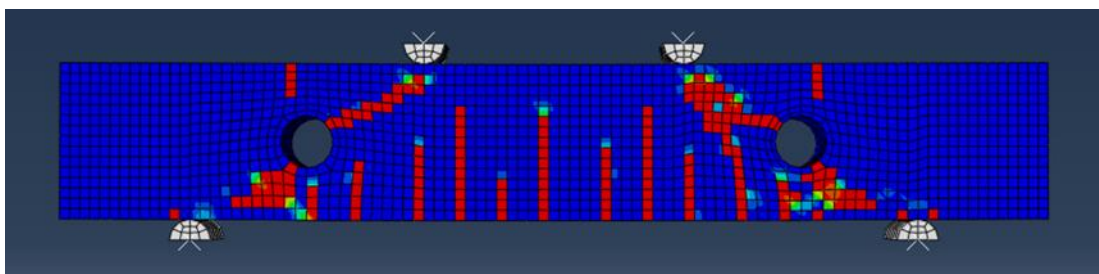


Fig. 9 Beam with 2 Openings (B-02) Crack Pattern

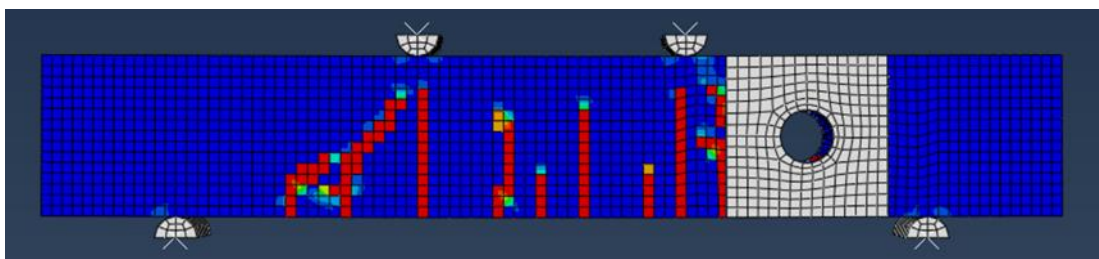


Fig. 10 Beam with 1 Opening with CFRP Sheet (B-01-SCS) Crack Pattern (CFRP Visible)

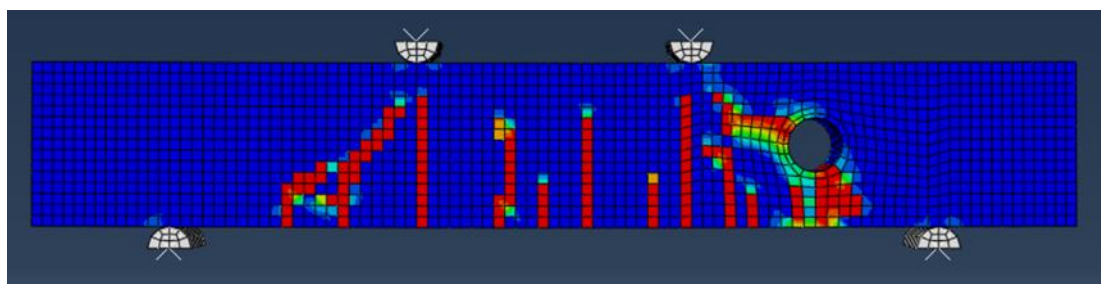


Fig. 11 Beam with 1 Opening with CFRP Sheet (B-01-SCS) Crack Pattern (CFRP Invisible)

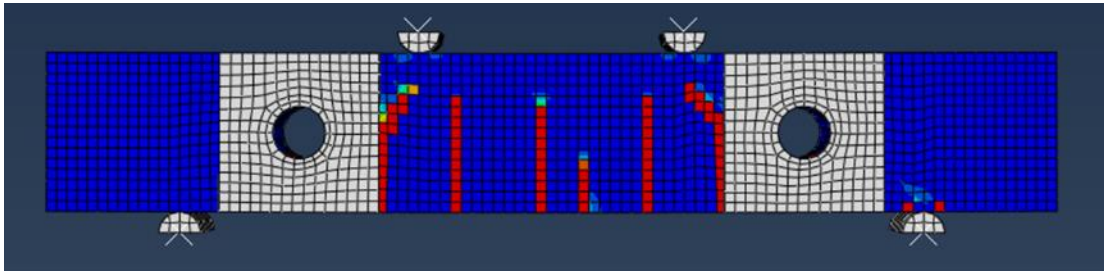


Fig. 12 Beam with 2 Openings with CFRP Sheet (B-O2-SCS) Crack Pattern (CFRP Visible)

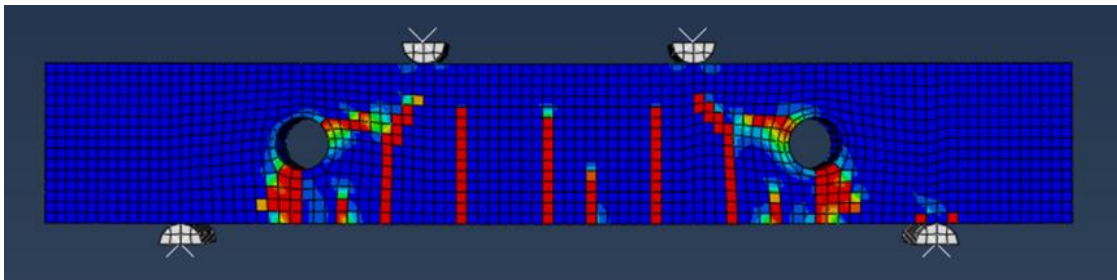


Fig. 13 Beam with 2 Openings with CFRP Sheet (B-O2-SCS) Crack Pattern (CFRP Invisible)

From fig. 7 until fig. 13 show that the crack pattern of the control beam indicates that the failure is located in the mid-span with flexural failure of the beam, while the other specimens that contain openings are located in the shear zone with shear failure for the crack pattern. Shear-zone failure is caused by the openings. The stiffness around the circular openings is relatively less compared to the solid part of the beam. Therefore, the distribution of loads are concentrated surrounding circular openings.

4. Conclusion

Finite Element Analysis for each specimen of the beam can be performed by using ABAQUS software. A circular opening causes the ultimate load of the beam to decrease significantly. The ultimate load of the beam with 1 opening decreases by 15.25% and the ultimate load of the beam with 2 openings decreases by 32.20% and there are significant improvements by using CFRP sheet strengthening to the beam. The ultimate strength of the beam with 1 opening is increasing by 16.00% and the beam with 2 openings is increasing by 35.00%. The crack pattern of the beam without an opening is concentrated in the mid-span of the beam with a flexural failure, while the other specimens have a shear failure within circular openings. Significant improvements in ultimate load conclude that using CFRP sheet to strengthen beam with circular openings are suitable.

The results of load-deflection profile calculated by Finite Element Modeling much higher than experimental results. The differences ultimate load results of Finite Element Method and Experimental are ranged from 2.94% until 9.87%. There are many factors and condition that are not considered in this study, for example, epoxy bonding of CFRP sheet and the time of increment load in ABAQUS are set to be 10 seconds, while in the experiment is more than one minute.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

References

- Salih, R., Zhou, F., Abbas, N., & Khan Mastoi, A. (2020). Experimental Investigation of Reinforced Concrete Beam with Openings Strengthened Using FRP Sheets under Cyclic Load. In *Materials* (Vol. 13, Issue 14, p. 3127). MDPI AG. <https://doi.org/10.3390/ma13143127>
- Mwendwa Mwonga, M., Kabubo, C., & Gathimba, N. (2023). Effect of polyethylene terephthalate fibres on the structural performance of reinforced concrete beams with openings in the shear region. In *Construction and Building Materials* (Vol. 369, p. 130539). Elsevier BV. <https://doi.org/10.1016/j.conbuildmat.2023.130539>
- Tahir, M., Wang, Z., Ali, K. M., & Isleem, H. F. (2019). Shear behavior of concrete beams reinforced with CFRP sheet strip stirrups using wet-layup technique. *Structures* 22, 43-52. <https://doi.org/10.1016/j.istruc.2019.08.001>
- SrIREkha, A., & Bashetty, K. (2010). Infinite to finite: An overview of finite element analysis. In *Indian Journal of Dental Research* (Vol. 21, Issue 3, p. 425). Medknow. <https://doi.org/10.4103/0970-9290.70813>
- Hemzah, S. A., Alyhya, W. S., & Hassan, S. A. (2020). Experimental investigation for structural behaviour of self-compacting reinforced concrete hollow beams with in-place circular openings strengthened with CFRP laminates. In *Structures* (Vol. 24, pp. 99–106). Elsevier BV.