Recent Trends in Civil Engineering and Built Environment Vol. 4 No. 1 (2023) 012-020

RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

Computational Study on Flexural Strengthening of Pre-cracks Reinforced Concrete Beams using Carbon Fibre Reinforced Polymer (CFRP)

Amira Balqish Sukri[1], **Koh Heng Boon**[1]*

[1,2]Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/rtcebe.2023.04.01.002
Received 06 January 2022; Accepted 15 January 2023; Available online 01 May 2023

Abstract: Carbon fibre reinforced polymer (CFRP) composite has been frequently utilized for shear and flexural strengthening of RC structures in recent times. However, there are little attention has been paid to study or research for combination of the length and position of the CFRP need to be used in order to strengthen the RC beams. The objective of this study is to model the pre-cracks reinforced concrete beams by using finite element method, to investigate the capacity and crack pattern of pre-cracks reinforced concrete beams strengthened by CFRP with different length and position and to analyse the optimum arrangement of CFRP on flexural strengthening of pre-cracks reinforced concrete beams by using finite element analysis. The pre-cracks reinforced concrete beams were analysed using LUSAS software. In the FEA, the pre-cracks reinforced concrete beams were modelled as 2D surface element subjected to an incremental concentrated load. Nonlinear concrete material and CFRP was assigned to predict the structural behavior of pre-cracks reinforced concrete beams in terms of capacity and crack pattern with different length and position of CFRP. From the FEA, it was found that the capacity of beams increased as the length of CFRP increased. The crack pattern mostly appear at tensile zone as flexure cracks and shear cracks pattern at support area.

Keywords: Pre-cracks RC Beams, CFRP, LUSAS

1. Introduction

One of the main factor is the flexural tensile strength of concrete, which are determine the deflection and cracking behaviour of concrete structures. Many factors that may affected the flexural strength of concrete, which are included age and concrete confinement, size of concrete structure, level of stress and many more [1]. According to the previous research, strengthening of reinforced concrete beams by using CFRP sheets can be greatly determines by properties, orientation and configuration of CFRP. The presence of CFRP sheets, which are externally bonded on RC structures, can increase the flexural strength in the range of 41 until 125% [2]. Based on the previous experimental studies, the researchers are more interested to carry out about the orientation of CFRP strips which are includes the magnitude

**Corresponding author: koh@uthm.edu.my*

of the increment and the direction of the carbon fibre reinforce polymer. However, there are little attention has been paid to study or research for combination of the length and position of the CFRP need to be used in order to strengthen the RC beams. By considerable amount of studies, the previous research also for both theoretical and experimental studies, have been investigated on the structural behaviour of FRP strengthened RC structures which are included beams, slabs and columns. Thus, the analysis of externally bonded CFRP strengthened RC beams using finite element analysis method has not received much attention and less addressed [3].

The use of fibre reinforced polymer (FRP) materials in civil engineering for restoration and strengthening of structural elements, as well as new construction, has become standard practise. Due to its high benefits, such as non-corrosive properties, low weight, greater ultimate strength, fast curing time, and simplicity of application, fibre-reinforced polymer (FRP) has attracted considerable attention in civil engineering applications [4]. The first parameter of FRP flexural strengthened beams is the number of layers. The quantity of FRP layers has a considerable impact on the behaviour of FRP flexural-strengthened beams. According to Arduini, increasing the number of FRP layers can contribute in enhances beam capacity [5]. The next parameter is the thickness of FRP. Stiffness and flexural strength increase as FRP thickness increases. With increasing FRP thickness, the failure mode shifts from plate-end debonding to intermediate-crack [6]. The latter investigation discovered that, up to a certain point, the load capacity rises with the thickness of the FRP plate. Beyond this point, increasing the FRP plate thickness did not result in an increase in flexure strength. In contrast, the FRP length of the beam also can be one of the parameters. It was stated by Hooque that there is a proportional relationship between FRP length and load bearing ability [7]. They stated that as the length of the FRP plate reduced, so did the load-carrying capacity and maximum deflection of the beam. The crack propagation is connected to changes in FRP plate length and resulting in beam failure modes varying. According to Al-Tamimi, a plate length need to design as equal to or more than 25% of the beam length to prevent debonding failures [8].

Therefore, the objective is to investigate the structural behavior of the pre-cracks reinforced concrete beams in term of capacity and crack pattern with different length and position by using finite element method, which is LUSAS software. In addition, this study is implemented to analyse the optimum arrangement of CFRP on flexural strengthening of pre-cracks reinforced concrete beams by using finite element analysis.

2. Methodology

The methodology used in this project will consists of the verification of the control beam, the parameter used for pre-cracks beam Series I and Series II, and the process of finite element modelling of pre-cracks beam.

2.1 Verification of control beam

In this study, the beam to be designed is 150 x 300 x 1960 mm of simply supported beam, which are reinforced with two steel bottom bars of 12 mm diameter and two steel top bars of 10 mm diameter. All the specimens that will be modelled are simply supported and the distance between the support and the concentrated load on beam is 520 mm as shown in Figure 1. The verification of control beam will be implemented to compare the results between the experimental studies done by Obaidat with this finite element analysis that will be conducted. Table 1 shows the area of reinforcing steel bars for RC beam.

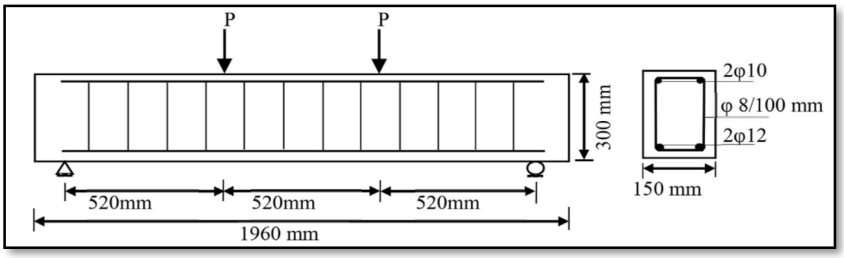


Figure 1: The cross-section of control beam in mm.

Table 1: The area of reinforcing steel bars for RC beam.

	Bar Size (mm)	Area of reinforcing steel (mm²)
Main Reinforcement	2H10	157
	2H12	226
	Bar Size (mm)	Sectional area per meter width (mm²/m)
Shear Link	H8-100	503

2.2 Modelling Pre-cracks Beam Series I

In this study, the propose thickness of CFRP plate is 1 mm and width is 150mm with different length and position as the objective of this study is to investigate the structural behaviour of pre-cracks reinforced concrete beams strengthened by CFRP with different length and position. The Table 2 shows the designation for dimension of CFRP meanwhile Figure 2 illustrate the beams strengthened with CFRP plate with 260 mm in length, which is single strengthening beam SS1.

Table 2: The designation for dimension of CFRP for Series I.

	Designation
Beam ID	CFRP (Length x Width x Thickness in mm)
SS1	260 x 150 x 1
SS2	520 x 150 x 1
SS3	1040 x 150 x 1
SS4	1560 x 150 x 1
SS5	1960 x 150 x 1

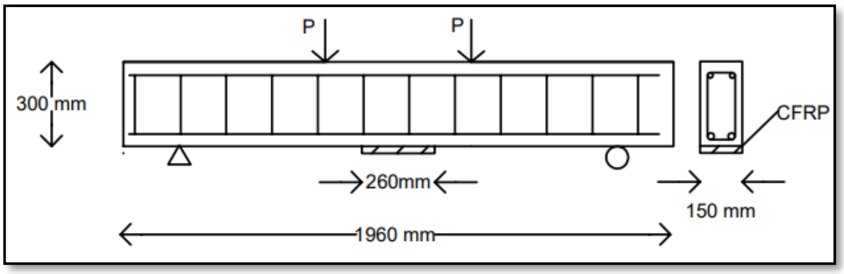


Figure 2: RC Beam strengthened with CFRP 260 mm in length at the bottom of beam.

2.3 Modelling Pre-cracks Beam Series II

The Table 3 shows the designation for Series II which are the CFRP located at bottom and side of beam with different height of CFRP at side, h. The dimension and material properties of beam are remain same as Series I. The Figure 3 illustrate the beams strengthened with CFRP plate with 75 mm in height and 1040 mm in length at the bottom, which is double strengthening beam DS1.

Table 3: The designation for dimension of CFRP for Series II.

Beam ID	Height of CFRP, h (mm)
DS1	75
DS2	150
DS3	225
DS4	300

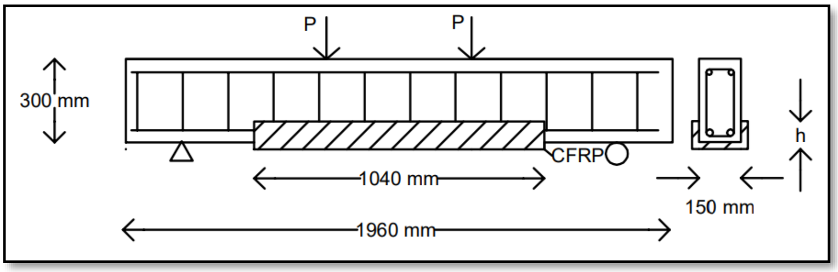


Figure 3: RC Beam strengthened with CFRP at bottom and side of the beam with 75 mm in height.

2.4 Material Properties

The material for the beam in this study is constant and have same material properties which are the compressive strength of concrete is 30 MPa meanwhile the mechanical properties of steel bars can be referred to Table 4. The Table 5 have shown the properties of CFRP sheet that will be applied to strengthen the RC beam.

Table 4: The mechanical properties of steel bars (Yasmeen Taleb Obaidat, 2011).

Parameter	Value	Value
Nominal Diameter (mm)	10	12
Elastic Modulus (Gpa)	211	207
Yield Stress (Mpa)	520	495
Ultimate Stress (Mpa)	741	760
Ultimate Strain	0.151	0.167

Table 5: Properties of CFRP sheet (Athira Appu, 2019).

Parameter	Value
Tensile Strength	4000 Mpa
Elongation	1.7%
Elastic Modulus	230 Gpa

2.5 Finite Element Modelling

In LUSAS Finite Element System, there are three main stages for the complete finite element analysis. The stages is including pre-processing, processing and post-processing.

2.5.1 Pre-Processing

Pre-processing stage involves construct geometrical modelling which represents of the structure and in this project it represents the beam and CFRP. This stage also involve assigning material properties, support, and loading.

2.5.2 Processing

When the modelling of structure is complete, the next stage is running the analysis or finite element solver. LUSAS will create the data file from the model generated. The outcome from finite element solver contains the required data needed such as stress, strain and displacement.

2.5.3 Post-Processing

Post-processing or results processing is the visualisation and manipulation of the results produced from an analysis. There are three types of analysis results, which is further calculations, manipulating the model and visualising results. Visualising results is including graph, contour plots, vector plots, deformed mesh and diagrams. In this project, the visualising results will be analysed.

3. Results and Discussion

Table 6 shows the results for verification of control beam meanwhile Figure 4 shows the final capacity for control beam. The Figure 5 show the the first cracks appears on the control beam with tensile crack pattern.

Table 6: The summary for the verification of the control beam.

	Experimental Load (kN)	Numerical Load (kN)	Percent difference (%)
Final Capacity	118	127	7.6

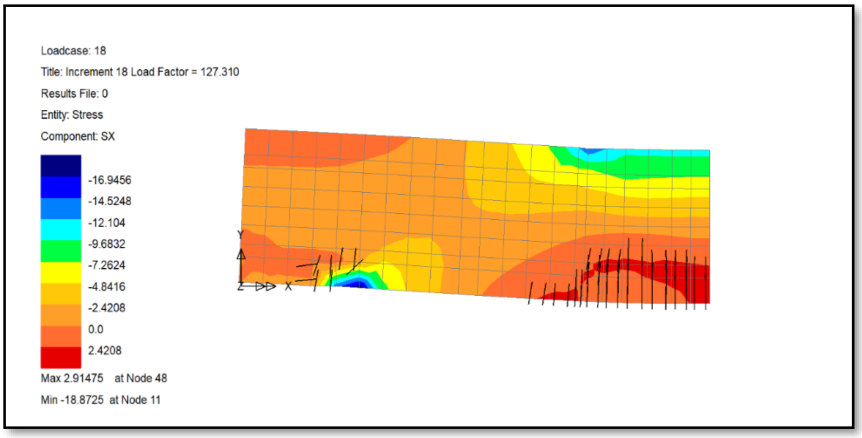


Figure 4: The final capacity for control beam, which is the maximum load is 127 kN.

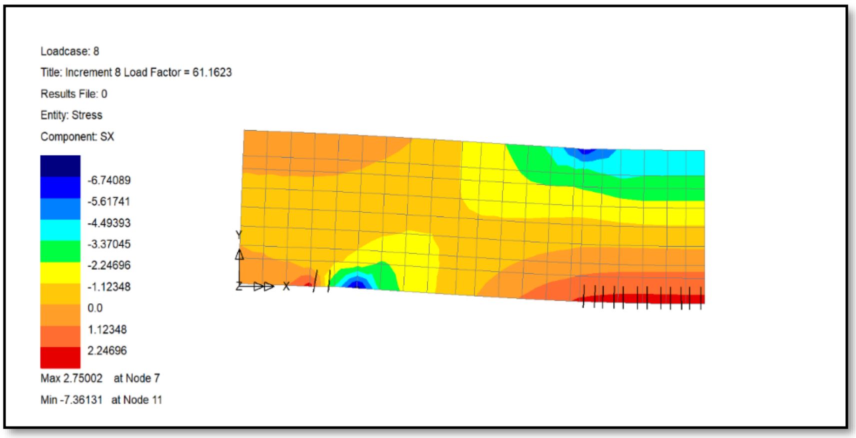
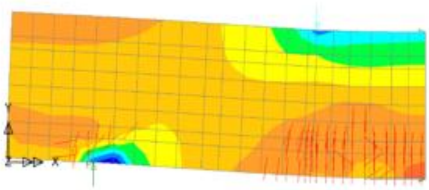
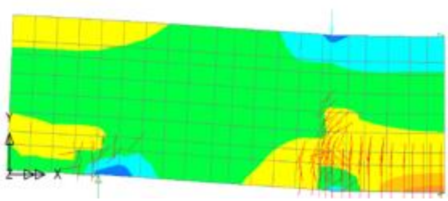


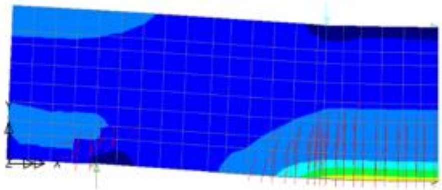
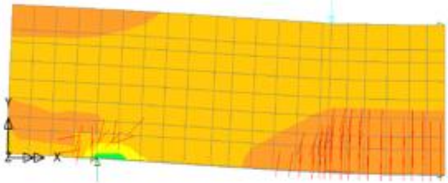
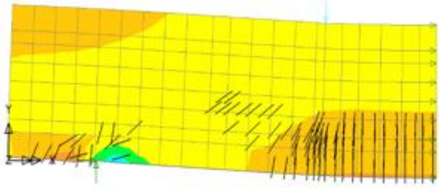
Figure 5: The first cracks appears on the control beam at 61 kN.

3.1 Strengthened Beam Series I

Table 7 shows the results outcome from FEA for Series I, which consists ultimate capacity, percent capacity increased, displacement factor and crack pattern. By referring the result shown, the ultimate capacity obtained for single strengthening beam increase, which is 149 kN, 152 kN, 175 kN, 190 kN and 239 kN. These ultimate capacity is higher compare to the ultimate capacity for control beam, which is 127 kN. Based on these results, the percent of capacity for single strengthening beam is increasing by comparing with the control beam, which is 17.3%, 19.7%, 37.8%, 49.6% and 88.2%. According to Hooque [7], there are a proportional relation between the length of FRP and the load carrying capacity. They stated that as the length of the FRP plate reduced, so did the load-carrying capacity and maximum deflection of the beam. Up to a certain point, the increase in FRP contribution is proportional to the increase in FRP length.

Table 7: The results outcome from FEA for Series I.

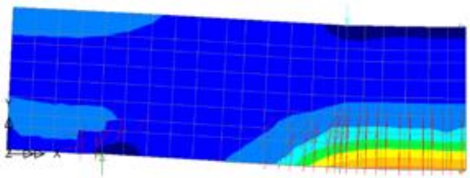
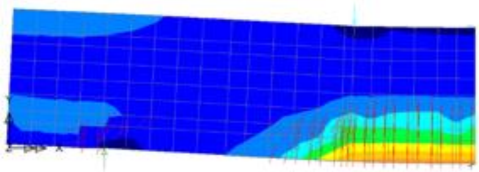
Single Strengthening Beam	Ultimate Capacity (kN)	Percent Capacity Increased (%)	P max / Δ max	Crack Pattern
SS1	149	17.3	2.16	
SS2	152	19.7	2.24	

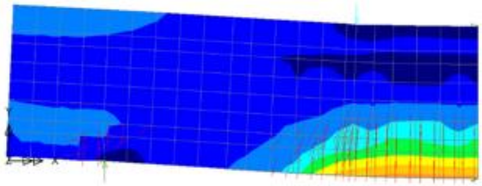
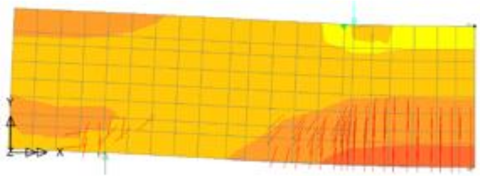
Single Strengthening Beam	Ultimate Capacity (kN)	Percent Capacity Increased (%)	P max / Δ max	Crack Pattern
SS3	175	37.8	2.22	
SS4	190	49.6	2.47	
SS5	239	88.2	2.39	

3.2 Strengthened Beam Series II

Based on the result, the ultimate capacity obtain for double strengthening beam is increase for DS1 and DS2 but then decrease for DS3 and DS4, which is 185 kN, 191 kN, 187 kN, and 123 kN. These ultimate capacity is higher compare to ultimate capacity for single strengthening for SS3, which is 175 kN. Based on these results, the percent of capacity for double strengthening beam is increasing and then decrease by comparing with the single strengthening for SS3, which is 5.7%, 9.1%, 6.9%, and -29.7%. Theoretically, the additional of CFRP at the side of beam will give enhancement to the shear cracks but less significant for flexural strengthening. Table 8 presents the results outcome from FEA for Series II.

Table 8: The results outcome from FEA for Series II.

Double Strengthening Beam	Ultimate Capacity (kN)	Percent Capacity Increased (%)	P max / Δ max	Crack Pattern
DS1	185	5.7	2.20	
DS2	191	9.1	2.12	

Double Strengthening Beam	Ultimate Capacity (kN)	Percent Capacity Increased (%)	P max / Δ max	Crack Pattern
DS3	187	6.9	2.17	
DS4	123	-29.7	1.48	

4. Conclusion

At the conclusion of this project, it can be declared that all of the study's objectives were met effectively using finite element analysis. Using LUSAS Software, all 10 types of beams, including the control beam, were successfully analysed. By comparing all of the specimens in terms of percent capacity increased, crack pattern, and displacement factor, the data is analysed. LUSAS software was used to simulate all of the pre-crack reinforced concrete beams. The whole specimens, including the control beam, were then evaluated in terms of capacity and cracking pattern in terms of structural behaviour. Based on the results, the optimum arrangement of CFRP on flexural strengthening of pre-cracks reinforced concrete beams by using finite element analysis for single strengthening beam was beam SS5 meanwhile for double strengthening beam was beam DS2. From the results, it can be concluded that the increase of CFRP in length can increase the increment of the strengthened Beam.

References

[1] M. Ahmed, J. Mallick and M. Abul Hasan "A Study of Factors Affecting the Flexural Tensile Strength of Concrete," Journal of King Saud University-Engineering Sciences, pp. 147-156, 2016.

[2] Y. Murad, "An Experimental Study on Flexural Strength RC Beams using CFRP Sheets," International Journal of Engineering & Technology, vol. 7, no. 4, pp. 2075-2080, 2018.

[3] J. Jayaprakash, A.A. Abdul Samad, Koh H. B, Anwar M. P1 and N. Mohamad "Experimental and Finite Element Studies on CFF Strengthened RC Rectangular Beams in Shear," International Journal of Integrated Engineering, vol. 7, no. 1, pp. 29-38, 2015.

[4] K. Rashid, X. Li, J. Deng, Y. Xie, Y. Wang and S. Chen, "Experimental and Analytical Study On The Flexural Performance of CFRP- Strengthened RC Beams strengthened RC beams at various pre-stressing levels," Composite Structures, vol. 227, pp. 111323, 2019.

[5] M. Arduini and A. Nanni "Behavior of Precracked RC Beams Strengthened with Carbon FRP Sheets," Composites for Construction, vol. 1, no. 2, pp. 63-70, 1997.

[6] R. A.-M. H. Pham, "Experimental Investigation Into Flexural Retrofitting of Reinforced Concrete Bridge Beams using FRP Composites," Composite Structure, vol. 66, pp. 617-625, 2004.

[7] M. Hooque, "3D Nonlinear Mixed Finite-element Analysis of RC Beams and Plates with and without FRP Reinforcement," Manitoba, Canada, 2006.

[8] A. K. Al-Tamimi; R. Hawileh, J. Abdalla and H. A. Rasheed, "Effects of Ratio of CFRP Plate Length to Shear Span and End Anchorage on Flexural Behavior of SCC RC Beams," Composites for Construction, vol. 15, no. 6, pp. 908-919, 2011.