Enhancing the Performance of Reinforced Concrete Beam Structure Using CFRP and CFRP Anchor

R Ariyansyah¹, R Gunadi², I A Reski¹, and I Rosanti¹

¹ Department of Civil Engineering, Pontianak State Polytechnic - Indonesia
² Department of Civil Engineering, Bandung State Polytechnic - Indonesia
*Corresponding author’s: ronaariyansyah99@yahoo.co.id

Abstract. Structural problems related to damage and failure of the buildings. Some methods have been commonly applied to enhance the capacity of a building structure through strengthening and repair by enlarging the dimensions of the structure, reinforcing it using steel plates, applying external pre-stressing, and carbon fiber-reinforced polymer (CFRP). CFRP is alternative material for reinforcing building structures. Unfortunately, debonding failure often occurs in the use of CFRP unless special treatment is applied for more optimal reinforcement capability. In this experimental study, CFRP with an anchor system made of CFRP was applied in concrete reinforcement. This experimental laboratory study was done through a series of scientific procedures to explain the problems and propose a proper solution. The test object in this study was a beam of 150 mm x 200 mm x 3200 mm size with a third point load. The variables in this study were different distances between anchors at 0.000 mm, 1200 mm, 800 mm, 400 mm, 200 mm. The results showed that the CFRP anchor applied within 1200 mm successfully increased the strength capacity by 33.910%. The use of anchor solved debonding problems regarding the use of CFRP. The use of CFRP anchors within 1200 mm distance was found as the most effective method in the use of anchors.

1. Introduction
Reinforced concrete structures are numerously used in the world of construction, such as the construction of bridge infrastructure, namely structural elements of plates, beams (girders), columns (pillars), and under structures, namely foundations. Building structures that have been well planned and built, sometimes have problems after they are put into use. The problems are on structure with damage and failure in buildings. Damage that occurs in reinforced concrete structures can be in the form of cracks in beams, columns, and slabs. Cracks in reinforced concrete structures will cause the steel reinforcement to experience corrosion due to environmental influences such as salt, chemicals, and humidity so that the structure decreases in strength, stiffness, service life, and concrete failure which in turn can lead to structural failure [1]. Corrosion to reinforcement and improperly designed reinforced concrete structures deteriorate over time [2].

To overcome this damage, a method is needed to increase the capacity of the building structure by strengthening and repairing the structure. Several methods of reinforcement and repair, such as adding a layer of concrete, reinforcing with steel plates, external pre-stressing, and using FRP (Fiber Reinforced Polymer) [3]. External reinforcement technology has demonstrated the ability to be a practical and effective way to reinforce concrete structures [4]. The method of strengthening and repairing reinforced concrete structural elements is expected not to interfere with the performance and
function of a structure, so it is necessary to have a fast, effective, material availability, simple and easy to implement the method of strengthening and repair in the field [5].

One of the methods used for strengthening and repairing reinforced concrete structures is using FRP material. FRP provides easy mobilization, easy installation in the field, relatively low installation costs, flexible materials, and is suitable for use in all construction frameworks. Fiber Reinforced Polymer (FRP) has higher tensile strength and stiffness than steel plates, Fiber Reinforced Polymer (FRP) is very simple in installation and lighter than steel plates. FRP is also resistant to corrosion. Despite the relatively high price, FRP provides the most economical solution for retrofitting as it can dramatically reduce labor costs [3]. The use of FRP has been accepted as an alternative material for structural reinforcement externally consisting of three types, namely Glass Fiber Reinforced Polymer (GFRP), Carbon Fiber Reinforced Polymer (CFRP), and Aramid Fiber Reinforced Polymer (AFRP)[6].

Several previous studies have shown that the concrete bond with FRP sometimes fails, namely in the form of breaking the bond between FRP and the concrete surface. The reinforcement of beams with FRP will experience debonding failure if there is no special roughness treatment on the concrete surface to be reinforced with FRP [7]. The debonding failure that occurred resulted in the ability of FRP reinforcement to the concrete beam not working optimally. The type of adhesive (epoxy), the dimensions of the attachment, and the method of surface treatment greatly affect the bond strength between the FRP and the concrete [8][9]. Debonding generally starts with bending or shear cracks in the moment area, spreading to the end of the FRP, and crushing the top of the concrete beam due to the stress on the concrete. There are several types of debonding failures in reinforcement using FRP such as debonding at the FRP end, intermediate crack (IC) debonding, concrete blanket separation, critical diagonal crack (CDC) debonding, and debonding on shear reinforcement [10]. Debonding occurs because of the initial crack in the middle of the span and is characterized by the appearance of shear cracks in the bearing area and spread to the middle of the span[11].

To prevent debonding is to install anchors using FRP with a U-jacket installation pattern. Also, the anchor installation can function to change the debonding failure to FRP failure [10]. The use of an anchor at the end of the CFRP with the CFRP U-jacket system can delay or prevent the separation of the concrete cover [12]. Therefore, an experimental study of reinforced concrete beams was carried out using CFRP with an anchor system made of CFRP. The purpose of this CFRP anchor system is to overcome debonding on the reinforcement with CFRP.

2. Methodology

In this study, the test object in the form of reinforced concrete beams with beam dimensions of 150 mm x 200 mm x 3200 mm of 5 pieces with each beam reinforced with 3 layers of CFRP, can be seen in Table 1. The specimen consisted of 1 control beam reinforced with 3 layers of CFRP (BF). 1 beam with 3 layers of CFRP reinforcement and added 3 CFRP anchors with an anchor distance of 1200 mm (BF-A1200). 1 beam with 3 layers of CFRP reinforcement and added with 4 CFRP anchors with an anchor distance of 800 mm (BF-A800). 1 beam with 3 layers of CFRP reinforcement and added with 7 CFRP anchors with an anchor distance of 400 mm (BF-A400). 1 beam with 3 layers of CFRP reinforcement and added 13 CFRP anchors with 200 mm anchor distance (BF-A200). The diameter of the used CFRP anchor was 10 mm with the anchor depth 50 mm. The number of reinforcements in each beam is 2 pieces in the compression area with a diameter of 13 mm (2D13), 2 pieces of reinforcement in the tensile area with a diameter of 13 mm (2D13), and the shear reinforcement uses a diameter of 8 mm (Ø8).
Table 1. Test Object Variable.

|                  | Number of CFRP Layers | CFRP Carriage Distance (mm) | Number of Anchors CFRP | CFRP Anchor Diameter (mm) | Depth CFRP Anchor (mm) |
|------------------|-----------------------|-----------------------------|------------------------|---------------------------|------------------------|
| BF               | 3                     | -                           | -                      | -                         | -                      |
| BF-A1200         | 3                     | 1200                        | 3                      | 10                        | 50                     |
| BF-A800          | 3                     | 800                         | 4                      | 10                        | 50                     |
| BF-A400          | 3                     | 400                         | 7                      | 10                        | 50                     |
| BF-A200          | 3                     | 200                         | 13                     | 10                        | 50                     |

The illustration of specimen design for a reinforced concrete beam with CFRP reinforcement and CFRP anchors (BF, BF-A1200, BF-A800, BF-A400, and BF-A200) is presented in Figure 1, 2, 3, 4, and 5.

**Figure 1.** Test object illustration (BF Beam)

**Figure 2.** Test Object Illustration (BF-A1200 Beam)
Figure 3. Test Object Illustration (BF-A800 Beam)

Figure 4. Test Object Illustration (BF-A400 Beam)

Figure 5. Test Object Illustration (BF-A200 Beam)
Reinforced concrete beam specimen making begins with cutting reinforcing steel, bending reinforcing steel, assembling reinforcing steel, then manufacturing and assembling formwork, installing strain gauges on reinforcing steel, and then casting and treating specimens. When the concrete reaches the age of 28 days, the beam specimen is cleaned on the side to be reinforced with FRP by using a grinding machine (figure 1). Next, apply the primer resin to the cleaned concrete surface and let it dry for long + 24 hours (figure b). Then the installation of 3 layers/sheet of CFRP, each layer of CFRP installation takes a minimum of 30 minutes for the Encapsulation Resin drying process (figure 3). The process of installing CFRP can be seen in Figure 6.

Figure 6. The CFRP Installation Process

After the CFRP Sheet is installed and has hardened for 24 hours, then proceed with the CFRP anchor installation work. For anchor installation, drilling holes for the anchor in the test object with a diameter of 10 mm and a depth of 50 mm and cleaning the anchor holes. Subsequently, the anchor mixing process is carried out by using Nitobond EC Adhesive, and then the adhesive is poured into the anchor holes (figure a). The pouring of the adhesive was followed by the installation of CFRP anchors (figure b and figure c). The process of installing CFRP anchors can be seen in Figure 3.

Figure 7. The process of Installing CFRP Anchors

2.1 Equipment Set up and Testing
Set The equipment set-up and the test are illustrated in Figures 4 and 5, where the specimen is placed on the loading frame with the rollers at both ends. The loading is carried out at 1/3 length of the beam of reinforced concrete with a distance of 1000 mm from the pedestal. Loading is done with the help of a hydraulic jack and load cell. To find out the amount of deflection that occurs during the test, 3 pieces of Linear Variable Displacement Transducer (LVDT) are installed on the test beam. One LVDT is installed in the lower half of the span and one each is installed in 1/3 of the span under the load on the left side and the load on the right side. For strain on longitudinal reinforcement and concrete surfaces, several strain gauges are installed in certain positions.

The beam test was carried out with Third-Point Load on the beam according to the ASTM C78-08 standard. The beam is loaded with a static (monotonic) load with a constant ramp actuator speed of 0.05 mm/s until the beam collapses. Data readings in the data logger are taken in stages with an increase in the load-interval of 0.05 mm/s. Meanwhile, observations on beam testing are continuously
monitored visually, especially on the development of cracks that occur due to additional loads, as well as on the behavior of the collapse that occurs. The loading on the specimen is carried out until the compressed area on the beam is destroyed and has reached the ultimate load. The equipment set-up plan and the main test objects can be seen in Figure 4 and Figure 5.

3. Results and Discussion
3.1 Strength
The results of the beam bending test using the third point load method shown the performance improvement with the reinforcement using CFRP and anchors was not uniform. In general, the test results show an increase in beam performance due to reinforcement using CFRP both without anchor and anchor. The results of the whole beam test are shown in Figure 10.
The beam test results showed that the highest softening condition occurred in BF-A1200 specimen. Therefore, the strengthening in the CFRP of the test specimen became brittle. However, it can increase the strength and stiffness of the beam specimen.

![Curves Load-Deflection Block Test Object](image)

**Figure 10.** The Bending Test Load-Deflection Relationship Curve of The Beam

The variation of the increase in the value of the first crack load due to the load acting on each of the BF-A1200, BF-A800, BF-A400 specimens against the BF specimen was 33.910%, 33.427%, and 1.066%, respectively, while the BF-A200 beam decreased by 1.410%. The load capacity when the first crack occurs (Pp) on each beam is presented in Table 2 and Figure 11.

| Object Test  | Crack Load First, Pp (kN) | Load Maximum, Pmax (kN) |
|--------------|---------------------------|-------------------------|
| BF           | 4.972                     | 21.168                  |
| BF-A1200     | 6.658                     | 21.541                  |
| BF-A800      | 6.634                     | 20.573                  |
| BF-A400      | 5.025                     | 18.878                  |
| BF-A200      | 4.902                     | 19.114                  |

**Table 2.** The Load Capacity of The Beam Bending Test Results

![First Crack Load Curve, Pp](image)

**Figure 11.** Load at First Crack

The increase in the maximum load that occurred on the BF-A1200 specimen against the BF specimen increased by 1.762%, while the maximum load that occurred on each of the BF-A800, BF-A400, BF-
A200 specimens decreased respectively by 2.811%, 10.818%, 9.703% for the BF specimen. This decrease was due to the increasing number of drilling holes that resulted in a reduction in the cross-sectional area of the beam and was the initial opening for cracks to occur.

3.2 Stiffness
The stiffness (Kp) of the first crack decreased in the BF-A1200 specimen by 5.129%, BF-A800 by 8.864%, BF-A400 by 8.522%, BF-A200 by 3.435% when compared to the BF specimen. This decrease is due to a reduction in the cross-sectional area of the beam due to drilling holes for the anchors. For more details, the stiffness value at the time of the first crack can be seen in Table 3 and Figure 12.

| Test Beam | Pp (kN) | δp (mm) | Kp (kN/mm) |
|-----------|--------|--------|------------|
| BF        | 4.972  | 6.717  | 0.740      |
| BF-A1200  | 6.658  | 9.481  | 0.702      |
| BF-A800   | 6.634  | 9.834  | 0.675      |
| BF-A400   | 5.025  | 7.421  | 0.677      |
| BF-A200   | 4.902  | 6.858  | 0.715      |

3.3 Crack and Collapse Patterns
Based on the research, the crack and collapse patterns that occur in each test beam are on the BF beam, the crack patterns that occur are in the form of shear cracks and flexural cracks, 21 shear cracks, and 28 flexural cracks with 2050 mm CFRP collapse. The crack pattern that occurred in the BF-A1200 beam consisted of 24 shear cracks and 31 flexural cracks with a 2000 mm CFRP collapse. The crack patterns that occurred in the BF-A800 beam consisted of 27 shear cracks and 31 flexural cracks with 1890 mm CFRP collapse. The crack pattern on the BF-A400 beam, there were 25 shear crack patterns and 35 flexural cracks. The collapse that occurred in CFRP was 1600 mm long, and the crack pattern that occurred in the BF-A200 beam consisted of 29 shear cracks and 34 flexural cracks with a collapsed length of 1550 mm FRP. Crack and collapse patterns can be seen in Figure 13.
Figure 13. Crack and collapse patterns.

4. Conclusions
The collapse of the CFRP reinforcement that occurred in the BF-A1200, BF-A800, BF-A400, and BF-A200 beams exceeded the thickness of the concrete cover, and some even exceeded the anchor depth. So it can be said that using an anchor with a depth of 50 mm with a diameter of 10 mm can overcome the debonding of the CFRP reinforcement. Meanwhile, the collapse in the BF beam is a debonding IC damage in the middle span area and a slip occurs at the end of the CFRP.

The number of cracks that occurred in each of the BF, BF-A1200, BF-A800, BF-A400, and BF-A200 beam the more anchor holes in a reinforced concrete beam using CFRP, the greater the reduction in the surface area of the beam in the tensile area. This will cause the initial opening for cracks to occur so that the number of cracks that occur will increase. To avoid a large number of cracks, it is necessary to pay attention to the problem of using the number of anchor holes and the depth of the anchor holes.

5. References
[1] H V S Gangarao, N Taly and P V Vijay 2006 Reinforced Concrete Design with FRP Composites (Francis: CRC Press)
[2] L Yan and N Chou 2012 Behavior and Analytical Modeling of Natural Flax Fibre Reinforced Polymer Tube Confined Plain Concrete and Coir Fibre Reinforced Concrete J. Composite Materials Vol. 47(17) 2133-2148
[3] J Tarigan, F M Patra, and T Sitiru 2018 Flexural strength using Steel Plate, Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) on Reinforced Concrete Beam in Building Technology Int. IOP Conf. Series: Earth and Environmental Science Vol 126(1): 012025
[4] C J Orbanich, P N Dominguez P N, and N F Ortega 2012 Strengthening and Repair of
Concrete Foundation Beams with Carbon Fiber Composite Materials J. Material and Structural Vol 45 (11) pp. 1693–1704

[5] R A Hawileh, H A Rasheed, J A Abdallaa, and A K Al-Tamimia 2014 Behavior of Reinforced Concrete Beams Strengthened with Externally Bonded Hybrid Fiber Reinforced Polymer Systems J. Materials and Design Vol 53 pp. 972-982

[6] M A Sultan, H Parung, M W Tjaronge, and R Djamaluddin 2015 Pengaruh Perkuatan GFRP-S terhadap Kapasitas Lentur Balok Beton Bertulang Publikasi Ilmiah S3 Teknik Sipil UNHAS, Maret. pp 81-90

[7] S Tudjono, H A Lie, and B A Hidayat 2015 An Experimental Study to the Influence of Fiber Reinforced Polymer (FRP) Confinement on Beams Subjected to Bending and Shear Int. Conf. of The 5th Euro Asia Civil Engineering Forum (Surabaya: Procedia Engineering) Vol 125 pp. 1070-1075

[8] H M Diab 2013 Performance of Different Types of FRP Sheets Bonded to Concrete Using Flexible Adhesive J. Sci and Tech. Vol 3 (2) pp. 116-126

[9] E B Dror and O Rabinovitch 2016 Size Effect in the Debonding Failure of FRP Strengthened Beams J. Eng. Frac. Mechanics Vol 156 pp. 161-181

[10] J G Teng, and J F Chen 2007 Debonding Failures of RC Beams Strengthened with Externally Bonded FRP Reinforcement Behaviour and Modelling Proceedings of the First Asia-Pacific Conference on FRP in Structures pp. 33-42. (Hong Kong: Polytechnic University)

[11] L Taerwe, L Vasseur, and S Matthys 2009 External Strengthening of Continuous Beams with CFRP Int. Conf. on Concrete Repair, Rehabilitation and Retrofitting (The Netherlands: CRC Press)

[12] B Fu, J G Teng, J F Chen, and G M Chen 2017 Concrete Cover Separation in FRP-Plated RC Beams Mitigation Using FRP U-Jackets J. Composites for Cons. Vol 21 (2) pp. 1-13

Acknowledgments

For the assistance and support provided by the Center for Technology Research and Development of Roads and Bridges (PUSJATAN), as well as the assistance of CFRP and epoxy materials that have been provided by PT. Fosroc Indonesia to the author in conducting this research, the author is very grateful. Hopefully, in the future, we can collaborate again in research.