

Study on Bearing Capacity of Reinforced Concrete Beams Strengthened with Carbon Fiber Reinforced Polymer Sheet

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ABSTRACT

In this study, the strengthening effect of the carbon fiber reinforced polymer (CFRP) sheet was studied. Four groups of specimens were designed, each of which has three specimens. The specimens were strengthened with 0 layer of CFRP sheet, one layer of CFRP sheet, two layers of CFRP sheet, and three layers of CFRP sheet, respectively. An experiment was carried out through the third-point loading method. Compared with the unreinforced reinforced concrete (RC) beams, the load of the beams strengthened with CFRP sheet significantly increased. Taking the ultimate load as an example, compared with the RC beams, the RC beams strengthened with one, two and three layers of CFRP sheet increased by 7%, 19%, and 23%, respectively; under the same load level, the mid-span deflection of the beam reduced, and the anti-deformation ability significantly improved. The experimental results show that the CFRP sheet can improve the bearing capacity of beams and can be further applied in practical engineering.

1. INTRODUCTION

With the development of the economy, the construction industry has become more and more prosperous. With the emergence of new buildings, the reinforcement and reconstruction of old buildings have been paid more and more attention. For old buildings, with the increase of service life, it is inevitable that the bearing capacity and reliability will reduce. Reconstruction will consume a lot of financial resources and cause a waste of resources. In comparison, the maintenance and reinforcement of old buildings is a more reasonable choice [1]. Dewi [2] strengthened the beams externally by adding external tensile reinforcement and stirrups.

Through the comparative experiments of 12 original beams and 12 modified beams, it was found that the ultimate load of the beams increased after the reconstruction, the ductility and stiffness decreased, and the crack pattern changed. Alam et al. [3] studied the strengthening effect of Kenaf fiber-reinforced polymer (KFRP) laminates on reinforced concrete (RC) beams. Through the experiments on different RC beam samples, it was found that the KFRP laminates with the largest fiber content had high tensile strength, shear load, and ultimate failure load, and fewer cracks.

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Nguyen et al. [4] studied the textile reinforced concrete (TRC) and found its effectiveness in increasing the flexural capacity of beams through experiments and numerical studies. Qu et al. [5] analyzed the influence of steel plate reinforcement on the anti-explosion performance of beams and found that the cracks of beams mainly concentrated in the reinforcement area, and the number of cracks decreased under the effect of steel plate reinforcement. Through the experiment, it was found that the optimal size of steel plate reinforcement was about 80 cm, and the reinforcement at the top and bottom of the beam had the best effect. In this study, the effect of carbon fiber reinforced polymer (CFRP) sheet reinforcement on the bearing capacity of RC beams was mainly studied. The concrete research was carried out through the design of specimens and loading tests to understand the application possibility of the CFRP sheet in construction engineering better and provide some new ideas for building reinforcement.

2. BUILDING REINFORCEMENT METHOD

At present, reinforcement methods commonly used in old buildings are as follows.

1. Increasing section: in the side to be strengthened, the reinforcement is added, and the concrete is poured to increase the cross-section, so as to improve its mechanical performance. This method has a favorable effect on improving the deformation capacity of the structure, but the engineering quantity is large, and the aesthetics are poor.
2. External wrapping of steel: steel materials such as steel plate and steel bar were pasted on the structure [6, 7] to be strengthened using materials such as epoxy resin to improve its bending and shear resistance. This method is simple in construction and short in construction period but also requires a large amount of work.
3. Pre-stressed reinforcement: adding pre-stressed reinforcement to the outer side of the structure to be strengthened makes it become the main body with the original structure, which improves the overall performance of the structure. The method is suitable for the large-span bridges.
4. Support reinforcement: on one side of the structure to be strengthened, the support or joist is added to improve the bearing capacity and stiffness. The reinforcement effect is good, and the economy is high, but the support will affect the space of the structure, and the aesthetics are poor.
5. Fiber reinforcement: in addition to the structure to be strengthened, the mechanical performance of the structure can be improved by pasting fiber materials [8]. This method has the advantages of small construction amount and simple operation [9]. At present, glass fiber-reinforced polymer (GFRP) [10, 11], aramid fiber reinforced polymer (AFRP) [12, 13] and CFRP [14] are commonly used, among which CFRP is the most mature and widely used one [15, 16], and it is also the research subject of this paper.

3. MATERIALS AND METHODS

3.1. Experimental Materials

C40 cement was used, whose measured compressive strength was 39.6 MPa, tensile strength of was 3.76 MPa, and Poisson's ratio was 0.18; the coarse aggregate was gravel, and the fine aggregate was river sand, shown in Tables 1 and 2; the experimental water was tap water, the longitudinal reinforcement was HRB400, and the stirrup was HPB335, as shown in Table 3. The thickness of the CFRP sheet was about 0.381 mm, the tensile strength was 3560 MPa, the elastic modulus was 2.5 GPa, and the ultimate strain was 1.33%. The tensile strength, elastic modulus, and elongation of the adhesive were 45 MPa, 3800 MPa, and 1.88%, respectively.

Table 1. Gravel parameters

Gradation/mm	5-20
Apparent density (kg/cm ³)	2810
Bulk density (kg/m ³)	1360
Silt content/%	0.5
Water absorption/%	1.0

Table 2. River sand parameters

Fineness modulus	2.9
Apparent density (kg/cm ³)	2590
Bulk density (kg/m ³)	1420
Silt content/%	1.8
Water absorption/%	1.3

Table 3. Reinforcement parameters

	Longitudinal bar	Stirrup
Yield strength/MPa	444	376
Ultimate strength/MPa	678	531
Poisson's ratio	0.3	0.3

3.2. Specimen Preparation

Four groups of test specimens were made: one group was pure RC beams, RC-1, RC-2, and RC-3; one group was RC beams with one layer of CFRP sheet, CFRP1-1, CFRP1-2, and CFRP1-3; one group was RC beams with two layers of CFRP sheet, CFRP2-1, CFRP2-2, and CFRP2-3; the last group was RC beams with three layers of CFRP sheet, CFRP3-1, CFRP3-2, and CFRP3-3. Each group had three specimens. As shown in Table 4, the size of the test specimen was 100 mm × 200 mm × 1500 mm (Figure 1).

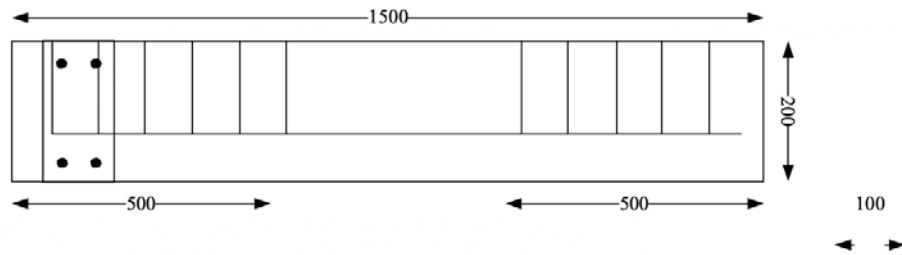


Figure 1. The structure of the test specimen

Before pasting the CFRP sheet, the surface of the RC beam was cleaned and polished with tools such as grinding wheel and sandpaper, the corner was treated into a smooth arc shape, and the surface was wiped and kept dry. The adhesive was smeared evenly on the position to be reinforced with a brush, and then the cut CFRP sheet was pasted and repeatedly squeezed to ensure that the CFRP sheet and RC beam are closely bonded, as shown in Figure 2.

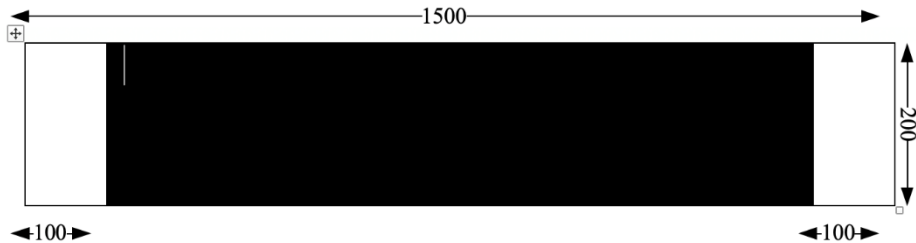


Figure 2. A RC beam strengthened by CFRP sheet

3.3. Experimental Methods

The steel bar strain and CFRP surface strain were measured using the third-point loading method (Figure 3) and strain gauge. Displacement meters were arranged at the beam support and mid span. The data were collected by the DH3816 system, and the crack development was recorded by a crack measuring instrument. 10 N was preloaded. After ensuring the normal operation of instruments, step loading was performed, and each level of loading was kept stable for 3 min. At the initial stage, 20 N was loaded every time until the concrete cracked. Then 50 N was loaded each time until the reinforcement yielded. Finally, 20 N was loaded each time until the concrete was crushed.

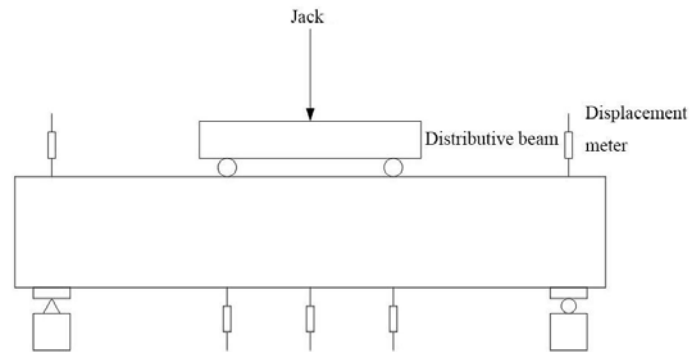


Figure 3. The loading device

4. EXPERIMENTAL RESULTS

4.1. Flexural Bearing Capacity

The results of the flexural bearing capacity of different specimens are shown in Table 4.

Table 4. Comparison of bending capacity

Specimen number	Cracking load/kN	Yield load/kN	Ultimate load/kN
RC-1	80.36	540.22	670.12
RC-2	81.28	541.36	671.28
RC-3	81.63	542.48	672.64
RC-average	81.09	541.35	671.35
CFRP1-1	85.49	600.77	721.33
CFRP1-2	84.67	602.46	720.58
CFRP1-3	85.78	604.51	721.49
CFRP1-average	85.31	602.58	721.13
CFRP2-1	100.64	674.62	800.58
CFRP2-2	101.37	674.23	801.64
CFRP2-3	101.64	675.81	801.25
CFRP2-average	101.22	674.89	801.16
CFRP3-1	105.27	693.48	827.66
CFRP3-2	106.78	694.55	827.61
CFRP3-3	105.81	694.68	828.57
CFRP3-average	105.95	694.24	827.95

It was seen from Table 4 that the flexural bearing capacity of pure RC beams was weak; the average cracking load was 81.09 kN, the average yield load was 541.35 kN, and the average ultimate load was 671.35 kN. After adding a layer of CFRP sheet, the bearing capacity significantly improved; the average cracking load was 85.31 kN, the average yield load was 602.58 kN, and the average ultimate load was 721.13 kN. According to Table 4, the more the layer of CFRP sheet was, the higher the flexural bearing capacity was.

To further understand the reinforcement effect, the average value of the RC beam was taken to compare the improvement amplitude of different specimens. The results are shown in Figure.

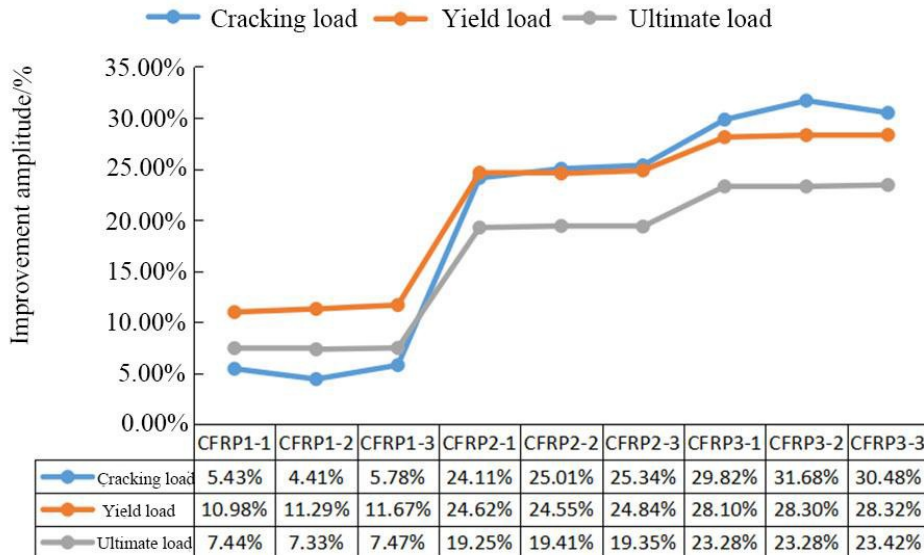


Figure 4. Comparison of improvement amplitude

It was seen from Figure 4 that after the reinforcement by one layer of CFRP sheet, the three kinds of loads improved by about 5%, 11%, and 7%, respectively; after the reinforcement by two layers of CFRP sheet, the improvement amplitude was 25%, 24%, and 19% respectively; after the reinforcement by three layers of CFRP sheet, the improvement amplitude was 30%, 28%, and 23% respectively. Generally speaking, when the number of reinforcement layers was three, the improvement amplitude flexural bearing capacity of the CFRP sheet was not as large as before.

4.2. Load Deflection Variation

The load-deflection variation of the specimens was analyzed, and the results are shown in Figure 5.

It was seen from Figure 5 that the maximum mid span deflection of RC beams was about 5 mm; after the reinforcement by one layer of CFRP sheet, the mid span deflection of RC beams significantly increased, and the maximum value has reached about 25 mm; however, with the increase of the CFRP sheet layers, the maximum deflection of the beam began to decrease, which indicated that the stiffness of the beams increased and the ductility gradually decreased; under the same load level, the more layers of CFRP sheet was, the stronger the anti-deformation ability of the beams was.

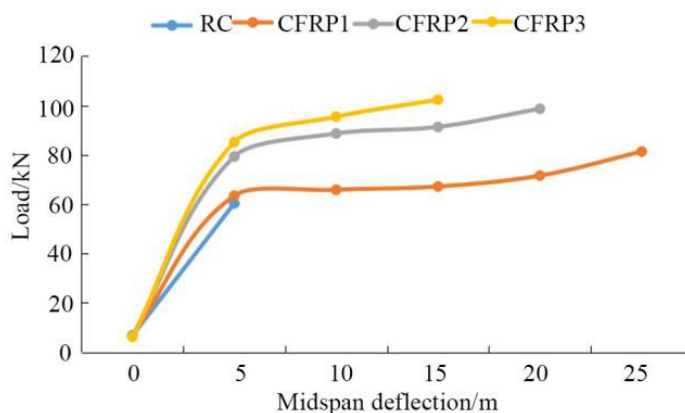


Figure 5. The load-deflection variation

5. DISCUSSION

Fiber materials have been widely used in construction [17]. Taking the CFRP studied in this paper as an example, it can be used in concrete structures in the form of bars to replace steel bars [18], which can be used in special environments such as the ocean and can also be made into composite plates for the bridge deck, roof, etc. [19]. Also, CFRP also has good conductivity [20], which can be used as an electromagnetic shielding plate and conductive board [21, 22]. Moreover, due to the low permeability [23], CFRP can be used as roof coating, impermeable, and corrosion-resistant [24]. The most commonly used CFRP is in the form of a sheet [25], which is pasted on the concrete surface for reinforcement. Compared with other fiber materials, the CFRP sheet is light and thin [26], with high strength and good applicability, which has obvious advantages.

To clarify the influence of CFRP sheet reinforcement on the bearing capacity of beams, four groups of specimens were designed by reinforcing 0, 1, 2, and 3 layers of CFRP sheet, respectively. It was found from the experimental results that the bearing capacity of the specimen increased with the increase of the number of CFRP sheet layers. Based on Table 4 and Figure 4, it was found that the ultimate load of pure RC beams was about 670 kN; the ultimate load increased to about 721 kN, 800 kN, and 827 kN after the reinforcement by one layer, two layers, and three layers of CFRP sheet. When the layer of CFRP sheet increased from 0 to 1, the ultimate load of the beams improved by about 7%; when the layer of CFRP sheet was two, there was an improvement of 19.34% in the ultimate load compared to the RC beams and improvement of 11.09% compared to the beams reinforced by one layer of CFRP sheet; when the layer of CFRP sheet was three, there was an improvement of 23.33% compared to the RC beams, an improvement of 14.81% compared to the beams reinforced by one layer of CFRP sheet, and an improvement of 3.34% compared to the beams reinforced by two layers of CFRP sheet. It was found that the reinforcement effect was not superposed with the increase of CFRP sheet layers. Then it was found that the deformation resistance of the beams was stronger with the increase of the number of CFRP layers under the same load level. In general, the more layers of the CFRP sheet were, the better the strengthening performance was. However, in the actual project, the actual demand should be fully considered to maximize the reinforcement effect of the CFRP sheet.

Although some achievements have been made in the study of CFRP, there are still some deficiencies. In the future works, the authors will

1. study the strengthening effect of the CFRP sheet on more different specimens;
2. analyze the long-term performance of RC beams strengthened with the CFRP sheet, such as durability and creep;
3. and study the effect of adhesive on the reinforcement performance of the CFRP sheet.

6. CONCLUSION

In this study, aiming at the problem of strengthening RC beams, the strengthening effect of CFRP with different layers is studied, and the specimens are designed and loaded. It was found that, with the increase of the CFRP sheet layers,

1. the flexural capacity of the specimens increased gradually;
2. the improvement amplitude of the flexural capacity decreased;
3. and the stiffness of beams enhanced, and the deformation resistance improved.

The experimental results verify the effectiveness of the CFRP sheet in strengthening RC beams, which is conducive to improving the bearing capacity of RC beams and can be further promoted and applied in practice.

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