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Bending performance of CFRP strengthened RC beams with different anchoring methods

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ABSTRACT: Bending performance experiments of CFRP strengthened RC beams with different anchoring methods are conducted, to study the ultimate bearing capacity, displacement, stress and cracks development of RC beams contrastively. The results indicates that : (1) A higher utilization of CFRP and ultimate bearing capacity is achieved when anchoring is applied; (2) When closing to ultimate bearing , the rate of "ultimate bearing capacity increasing" is higher, in the condition of anchoring at the middle of CFRP; (3) Anchor bolt has no effect on increasing of ultimate bearing capacity or "utilization of CFRP"; (4) Increasing numbers of anchoring plates are more effective on restraining the development of cracks; (5) Anchoring both at the middle and ends of CFRP plate is the best economic and effective way in all anchoring methods.

1 INTRODUCTION

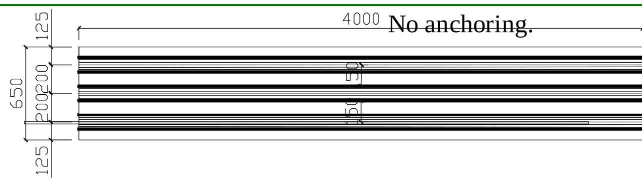
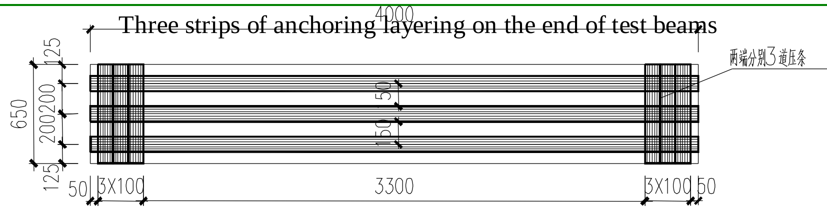
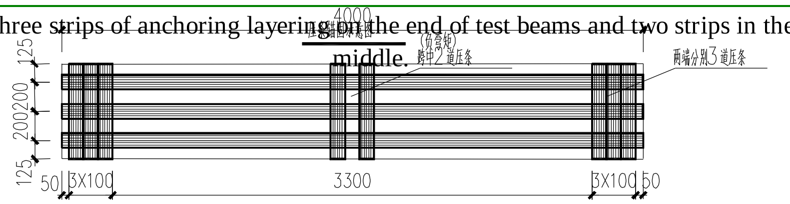
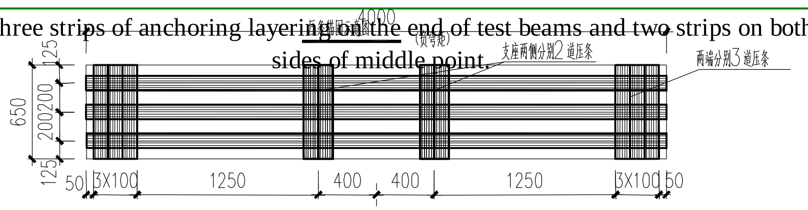
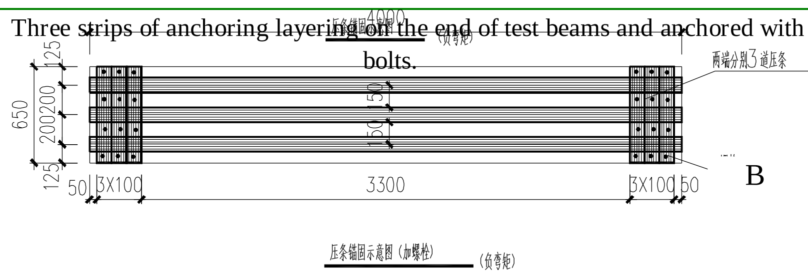
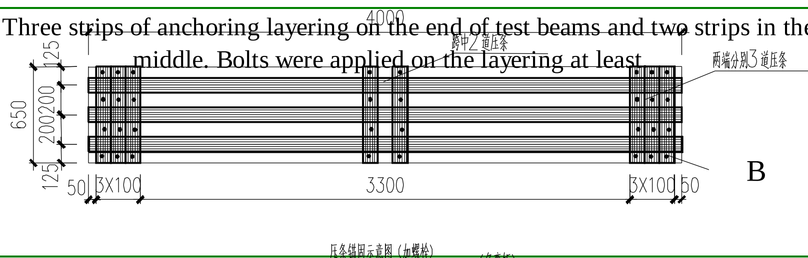
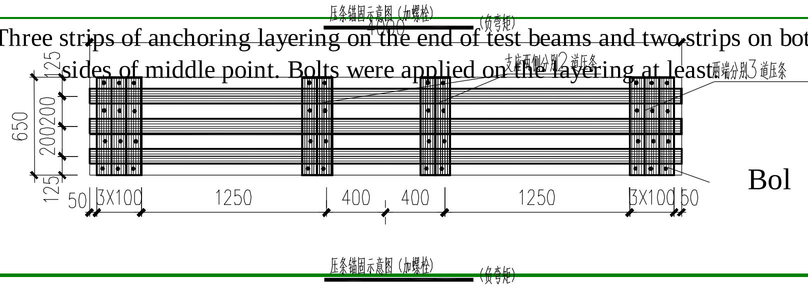
CFRP is used widely in strengthening of reinforced concrete structure due to the advantages of high-strength, light weight and easy workability. Many researchers domestic and overseas have focused on the failure type and performance of concrete beam strengthened with CFRP[1] under force, Brest[2], Gyuseon Kim[3], Islam[4], Sato[5] studied the affecting factor of shear failure at bonding surface in CFRP Reinforced concrete structures; Teng[6] studied reasons and failure type of CFRP peeled form the adhesive surface under ultimate load; Due to the failure types and low utilization of CFRP in reinforcement structure, scholars began to study the strengthening effect by anchoring method. Galal and Mofidi[7] developed a hybrid anchoring method to fixed the ends of CFRP which effectively prevented the peeling of CFRP and improved the ductility of reinforcement beams; Pellegrion, Modena[8] and Wu Yufei[9] did the same researches; Li Baozhong[10] studied the influence law of CFRP- concrete bonding interface by different sizes of anchoring "layering", and deduced a calculation model of CFRP- concrete interfacial adhesion properties with the anchor "layering", which based on the researches of KY Leung[11] and Matriculation[12]. The research results above show that anchoring can effectively improve reinforcement effect of CFRP reinforced concrete beam. Zhou Chaoyang[13], Li Weiwen[14] experimentalized and verified the effect of structure anchored by CFF (Carbon Fiber Fabric) based on the results of previous studies. While there were many studies focus on stress mechanism of CFRP strengthened concrete beams and theories of anchor "layering" function, but there is rarely experimental studies on the effects of conventional ways anchoring "layering" to ultimate load of CFRP reinforced concrete. In order to fully understand and improve this new reinforcement technology, based on existing research, the paper will illustrate the most cost effective anchoring methods by making concrete beams to go through the experiment of ultimate flexural carrying capacity contrastively, in which the CFRP reinforced concrete beams were anchored by six groups of different ways.

2 EXPERIMENTAL DESIGN AND LOADING METHOD

2.1 *Test Beam Size, Material and Anchoring Arrangement*

7 groups of RC test beam[15] were designed in experiments, the dimension of beams is: 400cm(in length)×65cm(in width)×28cm(in thick), and the concrete grade is C45. Two meshes made by φ12HRB400 rebar were configured in the beams.

Table 1. Methods of anchoring layering on test Beam

NO.	Methods of anchoring
N1	No anchoring. 
N2	Three strips of anchoring layering on the end of test beams 
N3	Three strips of anchoring layering on the end of test beams and two strips in the middle. 
N4	Three strips of anchoring layering on the end of test beams and two strips on both sides of middle point. 
N5	Three strips of anchoring layering on the end of test beams and anchored with bolts.  B
N6	Three strips of anchoring layering on the end of test beams and two strips in the middle. Bolts were applied on the layering at least  B
N7	Three strips of anchoring layering on the end of test beams and two strips on both sides of middle point. Bolts were applied on the layering at least  Bol

Unidirectional CFRP was adopted in the experiment, and the properties of CFRP were: tensile strength-2300MPa, tensile modulus – 150GPa, dimensions – 3900mm (in length) ×100mm (in width) ×1.4mm (in thick). Two-way CFRP was adopted as the anchoring layering which is 650mm in length. Φ12mm anchor bolts which yield tensile strength no less than 600MPA were applied. After sandblasting the surface, three strips of CFRP plates were applied parallelly in longitudinal direction and the gap of CFRP axis is 200mm.

Apply anchoring layering and bolts to CFRP strengthened concrete beams when the CFRP adhesive is cured. The dimensions of anchoring layering and bolts are shown as Table 1.

2.2 *Load Programs and Data Collection Methods*

Strain gage was applied at the locations of reinforcement in tensile zone(before casting of concrete), cracking zone at bottom and sides of beams, both sides of CFRP, when the curing days of anchoring layering were more than 7days. Symmetrical was applied on the test beams (as Figure 1and Figure 2). Load was applied in multi-stage, and each step was 15KN which applied continuously and slowly.

Equipment of displacement meter, static and dynamic strain measurement system and portable strain gauge device were adopted to collect the data of deflection, strains of reinforcement in tension zone and compression zone, and the strains of CFRP. Based on these data and situations of CFRP observed in the peeling zone, the ultimate load at de-bonding moment, the ultimate tensile strength of CFRP, and the percentage to maximum tensile of CFRP specimens were calculated. The development of cracks was observed by instruments and magnifying glass.

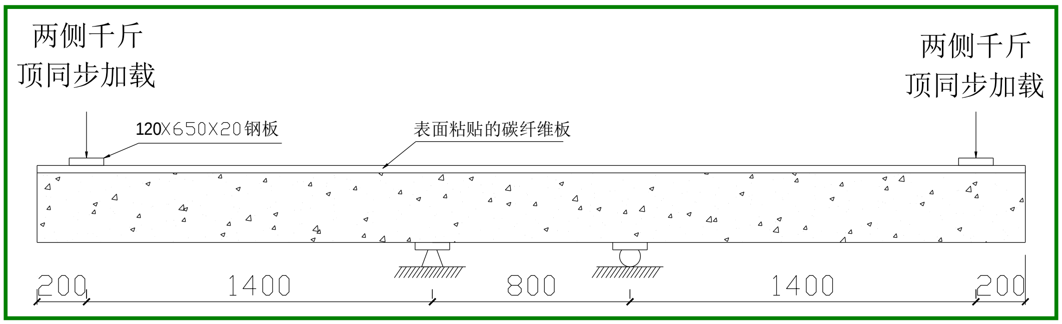


Figure 1. Load step on test beam

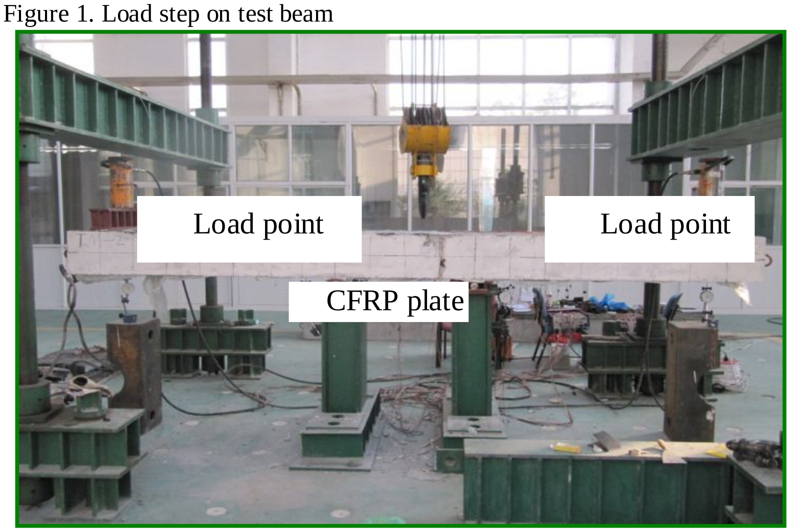


Figure 2. Photos of loading

3 TEST RESULTS AND ANALYSIS

3.1 *Development of Cracks*

Big sounds were heard when the load is 30% of ultimate load, and the sounds became louder as the increasing of load. When at the bending moment of 145Kn.m, CFRP and adhesive are peeling from the edge of concrete, and the peeling increased rapidly as the adding of load.

For N1, when the load reached 90% of ultimate load of unreinforced concrete beam, the CFRP was peeled in the middle and developed to ends of beam until ultimate load. Most areas of adhesive was peeled from concrete in the middle of beams, and a little at the ends. CFRP was peeled from adhesive in the end at most area.

For N2 & N3 & N4, CFRP was peeled in the middle but not in the end at the moment of ultimate load; For N2 & N3 & N4, CFRP was peeled in the place there is no anchoring layering at the moment of ultimate load; Comparison to N1, the ultimate load increased obviously for other six beams, and the tensile strength of CFRP were bigger than N1.

During the loading step, cracks developed fast at the initial stage for every beam. When the stress of CFRP increased obviously, the development of cracks slowed down and numbers of cracks stayed stable. In the end stage of ultimate load, the development of cracks was restrained by CFRP, and CFRP undertook the most of loads. Figure 3 shows the beam failed after ultimate load.

(a)

(b)

(c)

Figure 3. Beam failed after ultimate load

3.2 *Comparative Analysis of Cracks*

Figures 5 and 6 showed load-width curves of crack. As shown in Figure 5, maximum width of cracks of N3 was less than N2 by 46%, and the percentage is 16% for N4. Method of N3 was the most significant way in restraining crack development.

As shown in Figure 6, maximum width of cracks of N6 was less than N5 by 46%, and the percentage is 16% for N7. Method of N6 was the most significant way in restraining of cracks developing. Compared to N2 & N3 & N4, the method of anchorage by bolts (N5, N6, N7) didn't contribute to the restraint of cracks development.

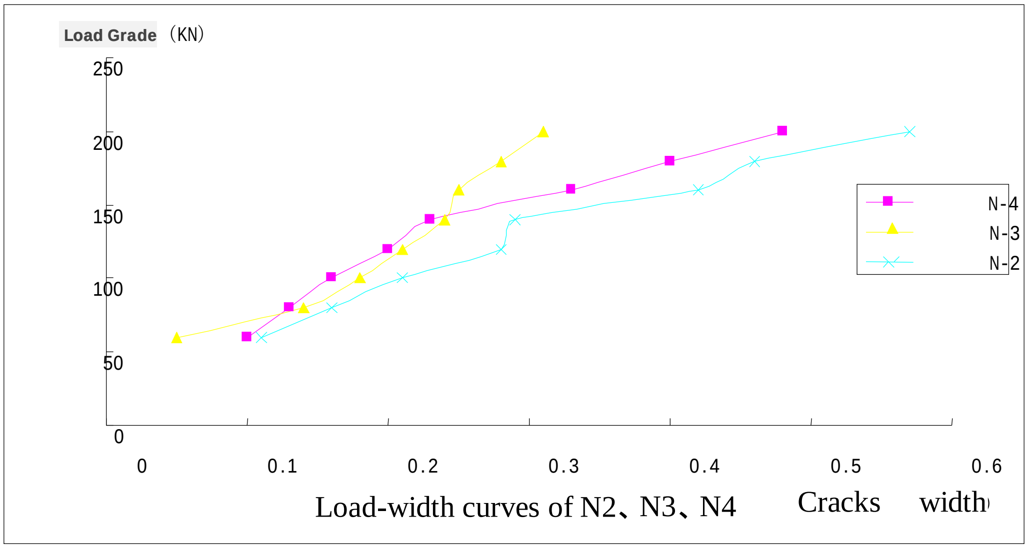


Figure 4. Load-crack width curves of N2、N3、N4

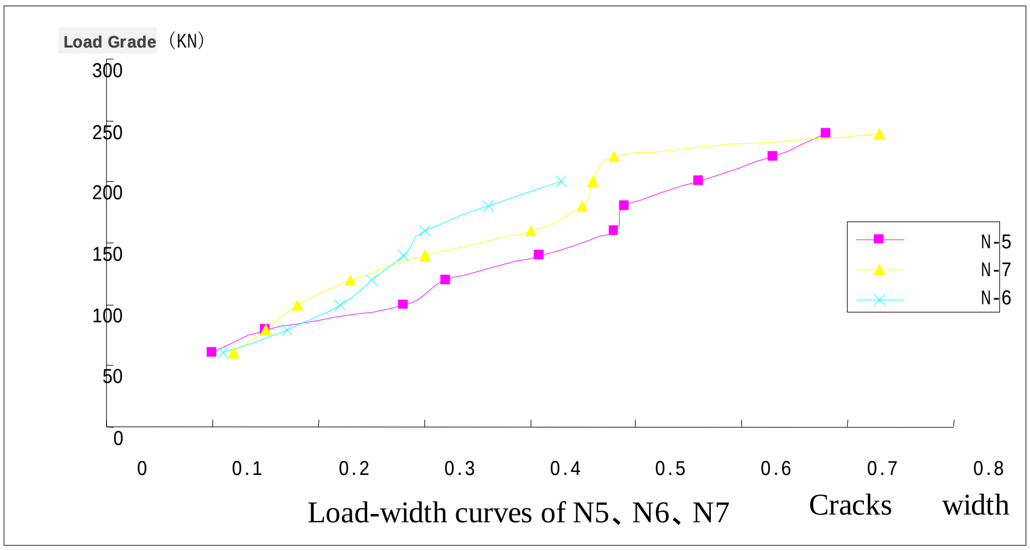


Figure 5. Load-crack width curves of N5-N6-N7

3.3 *Stress Analysis of Different Anchoring Methods*

Table 2 showed the maximum stress of CFRP at the moment of ultimate load according to test results.
As shown in table 2: Anchoring layering can significantly improve the ultimate bearing capacity of the beam by at least 32%, and also can largely improve the utilization of CFRP; the method of CFRP anchored by bolts didn't contribute strengthening of CFRP; anchoring both in ends and middle was the most cost-effective method.

Table 2. Maximum stress of CFRP at the moment of ultimate load

NO.	Ultimate load at the moment of CFRP peeling (KN)	Maximum stress of CFRP at the moment of ultimate load (MPa)	Percentage of max stress to tensile strength of CFRP
N1	180	589	25.61%
N2	242	873	37.96%
N3	283	1052	45.72%
N4	260	905	39.33%
N5	247	897	39.00%
N6	289	1081	46.98%
N7	266	921	40.04%

4 CONCLUSIONS

a. Anchoring layering can restrain the development of cracks significant, when close to the moment of ultimate load.
b. Anchoring layering applied in ends can significantly improve the ultimate bearing capacity of the beam by 32%, and improve the utilization of CFRP by 12.35%; Anchoring layering applied in both ends and middle can significantly improve the ultimate bearing capacity of the beam by 55%, and improve the utilization of CFRP by 20.11%; Anchoring layering applied in ends and both sides of middle point can significantly improve the ultimate bearing capacity of the beam by 44%, and improve the utilization of CFRP by 13.72%.
c. CFRP anchored by bolts increased the utilization of CFRP by 1% only, but it didn't contribute the ultimate bearing capacity of the beam.
d. Anchorage both in ends and middle was the most cost-effective way in all the anchoring methods.

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