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Research on flexural performance of damaged RC beams strengthened by FPR plates

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Abstract: Combining two technologies of pasting fiber reinforced composite board (FRP) and externally reinforced steel plate concrete structure, fiber-reinforced composite material and steel plate composite reinforced concrete structure technology can effectively improve the stress performance of concrete reinforced structure. To explore the effect of the new technology steel plate anchoring FRP slab concrete beams and the effect of different damage levels on the reinforcement effect, in this paper, the author made 3 FRP reinforced beams with damage rates of 20%, 40%, and 60%, 1 RC beam with FRP plate only and an ordinary RC beam to analyze the reinforcement effect of the new process steel plate anchored FRP plate and the bearing capacity and plastic performance of the reinforced beam with different damage rates. The results show that the new technology steel plate anchoring FRP plate reinforcement technology can effectively prevent the occurrence of early peeling failure, improve the ductility and bearing capacity of the reinforced beam, and significantly increase the utilization rate of the FRP plate; as the damage rate increases, the ultimate bearing capacity of the reinforced beam increases, but the ductility is significantly reduced.

1 Introduction

Since the 20th century, concrete structures have been widely used in construction, but nowadays, people have higher requirements for the use of buildings, in this case, the reinforcement of reinforced concrete structures is very important. Appropriate structural reinforcement methods can improve safety performance, greatly enhance the carrying capacity of the structure, and achieve good social and economic benefits.

The most common form of reinforcement is to use carbon fiber reinforced polymer (FRP) plates to reinforce bending members such as beams and plates. So far, the flexural performance of FRP reinforced components has been deeply studied at home and abroad, but most of [1] are tested without anchoring the components, and in actual reinforcement projects, the utilization rate of FRP plates is not high. In view of this fact, previous researches [2-6] show that: different reinforcement methods have a certain impact on the structural performance of members. Zhou Ting [7] combined the strengths of externally bonded FRP plates and steel plates in improving the mechanical performance of the structure, and combined FRP plates and steel plates to strengthen the flexural members. The purpose is to prevent the end and the middle carbon plate from peeling off, and to solve the problem of anchoring small steel sheets easy to cause the shortcomings of stress concentration on the FRP board, which makes the FRP sheet and the concrete bond better, and the material reaches the best utilization rate. Studies have shown that the bearing capacity and flexural rigidity of components are significantly improved after composite reinforcement, but the construction process is slightly complicated, and it is necessary to simplify the construction process.

For this reason, this experiment adopted a simpler steel plate anchoring method, and carried out bending tests on three steel-anchored FRP plate-reinforced RC beams under three different reinforcement methods and three reinforced beams with different damage rates to study the reinforcement members under different damages. The flexural performance and plastic performance of the steel, and the limit of increase in bearing capacity is discussed.

2 Experiment design

2.1 Component design

In this experiment, 5 reinforced concrete specimens were produced, numbered from L1 to L5, with geometric dimensions of 1600 mm× 200 mm× 150 mm. Two φ20 tension longitudinal bars were set on the bottom of the beam, and two φ10 vertical bars in the upper compression zone. The concrete protective layer is 25 mm thick. Stirrups were configured. Stirrups are distributed throughout the beam as φ10@120, as shown in Figure 1, and the beam parameters are shown in Table 1:

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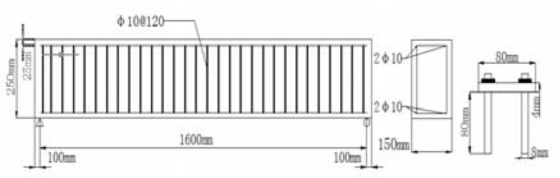


Fig. 1 The detailed dimensions and reinforcement diagram of the test piece and the anchor

Tab.1 Parameters of beams

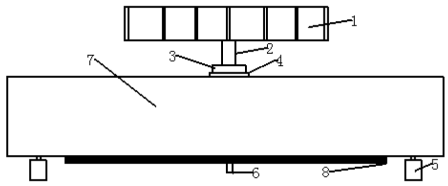
No.	Reinforcement	With or without FRP board	Damage degree
L1	/	/	0
L2	/	With (thickness 1 mm, width 5 cm)	40%
L3	Steel plate anchoring	With (thickness 1 mm, width 5 cm)	20%
L4	Steel plate anchoring	With (thickness 1 mm, width 5 cm)	40%
L5	Steel plate anchoring	With (thickness 1 mm, width 5 cm)	60%

2.2 Experimental materials

The concrete design strength value is C30, the mix ratio is 0.38:1:1:1:2.72, the measured average compressive strength of concrete is 34.5 MPa, and the elastic modulus $Ec=4.87\times10^4$ MPa. Fiber reinforced composite material (Fiber Reinforced Polymer/Plastic, referred to as FRP), FRP composite material is a high-performance material formed by mixing fiber material and resin in a certain ratio. The tensile strength of FRP is Rm=40.3 MPa, the tensile elastic modulus Ec=4920 MPa, the thickness of the carbon plate is 1 mm, and the width is 5 cm. The average yield strength of φ10 and φ20 steel bars is fy=357.10 MPa, and the elastic modulus Ec=210 GPa.
The anchor is composed of a steel sheet, two screws, nuts and washers of the same size, the anchoring distance is 20 cm, and the anchoring steel plate thickness is 4 mm. The detailed dimensions are shown in Figure 1.

2.3 Construction plan

There is a hole on both sides of the steel sheet, and the diameter of the hole matches the size of the screw. Firstly, after drilling a hole on the concrete specimen, we punched the anchor glue into the hole, then fixed the screw, and then pasted the FRP board at the designated position according to the external paste method, and then placed the steel plate on the pasted fiber cloth for compaction. Then we put the steel sheets of the mechanical anchor on the fixed screw in turn, and finally install the nut and washer on the screw. After the glue is cured, we use a torque wrench to apply torque to the nut.



1. Jack; 2. Sensor; 3. Solid steel pipe; 4. Support; 5. Displacement meter; 6. Test beam; 7. Carbon plate

Fig. 2 Beam loading diagram

2.4 Loading scheme

The RC beam flexural performance test adopts three-point symmetrical static loading. The loading device adopts PWS-500 electro-hydraulic servo fatigue tester to load uniformly along the width direction of the mid-span. During the test, a 4 cm solid steel pipe was set at the center of the test beam in order to transmit the line load. After resetting the instrument to zero, it is officially loaded. The load adopts a hierarchical loading mechanism with a loading step difference of 2 KN. After the loading is completed, the load is held for 5 minutes to observe the test phenomenon. When the specimen is deformed to that it cannot continue to bear the load or the concrete in the compression zone of the test beam is crushed, it is deemed to be broken and the load is stopped.

3 Test results and analysis

3.1 Different reinforcement methods

3.1.1 Test result

Comparing the three components of L1, L2, and L4, the L1 beam is an ordinary RC beam. When this component cracks, several vertical cracks appear in the middle of the specimen first; when the load reaches about 80% of the ultimate load, the crack width increases continuously. It can be seen from Figure 3 that the concrete in the compression zone is crushed; L2 is a single FRP RC beam without anchoring. The crack phenomenon is basically the same as that of ordinary concrete. When it is approaching failure, FRP begins to peel off at the wider crack position, and accompanied by a continuous sound. The peeling development is very rapid, until the FRP on one side is completely peeled off, as can be seen from Figure 4 that the carbon plate is not broken in the end; L4 beam is an RC beam anchored by steel plate, and the crack development law is very similar to L1. Before reaching the ultimate load, the carbon plate is always on the concrete surface, when approaching failure, the peeling rate is significantly slower than that of the L2 beam. It can be seen from Figure 5 that the carbon plate fractures during failure.

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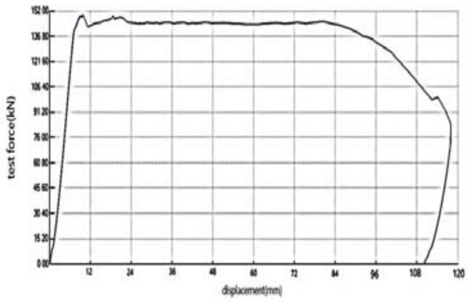
Fig. 3 crushing of concrete

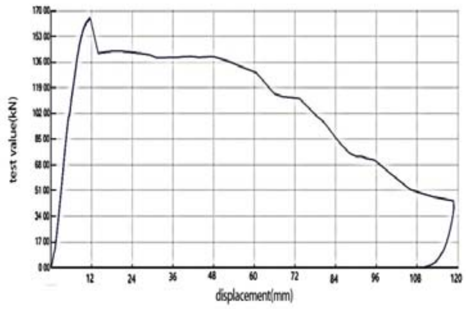
Fig. 4 carbon plate is not broken

Fig. 5 carbon plate is broken

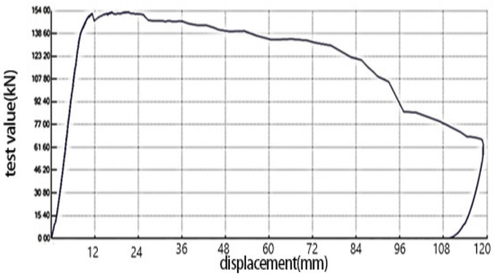
3.1.2 Mid-span deflection



(1) Ordinary RC beam



(2) RC beam with the 40% carbon plate damaged



(3) RC beam with the 40% anchoring damaged

Fig. 6 Load displacement curves of different reinforcement methods

Tab.2 Flexural capacity of FRP reinforcement

No.	Yield load	Ultimate load	Destruction mode
L1	130KN	140KN	Crushed concrete
L2	140KN	165KN	Carbon plate peeling
L3	133KN	138KN	Carbon plate fractured
L4	145KN	149KN	Carbon plate fractured
L5	150KN	160KN	Carbon plate

It can be seen from the three load-displacement curves that before the load reaches the beam cracking load of the specimen, the load value increases linearly with the displacement, and the three curves increase simultaneously, indicating that FRP reinforcement has no effect on the overall stiffness of the beam at this stage; Before the steel bar yields, it can be found that the slopes of the L2 and L4 curves become larger, indicating that FRP reinforcement improves the stiffness of the beam and increases the load-bearing capacity of the beam. The anchorage has no significant effect on the load-bearing capacity of the beam at this stage; The ultimate load values of L1, L2, and L4 are 140KN, 165KN, 149KN. FRP reinforcement increases the ultimate load value of the RC beam, and steel plate anchoring reduces the ultimate load value of the reinforced beam; after reaching the ultimate load, the carbon plate at the end of the L2 beam peels off and there's been a significant drop in the curve. Compared with Figure6(3), the anchoring method has delayed this trend. The specimens anchored with steel plates still maintain a high load-holding capacity; before failure, the anchored beams still maintain good plastic properties. After the beam reaches the ultimate load, the deflection of the reinforced beam still increases slowly, indicating that the beam’s bending resistance is still enhanced. After comparison, due to the enhancement effect of FRP reinforcement on the bending resistance of the beam, the ultimate load and mid-span deflection increase, and the final damage degree is more obvious.

3.1.3 Rebar strain

It can be seen from Figure 7 that the strain curve can be roughly divided into three stages. At the beginning of the load, the two curves show linear growth, indicating that the reinforced concrete, steel and FRP have a good coordinated deformation; when the load reaches about 20% of the ultimate load, the strain of the steel changes, which is because the concrete reaches the tensile bearing capacity It cracks at the limit value and exits work. At this time, the tensile force is borne by the steel bar or the steel-carbon plate, and the curve is close to the level; then the tensile steel bar yields, the concrete cracks widen, and the unreinforced concrete beam still maintains good ductility, but we can see that the yield point of the steel bar is obviously lagging behind, which indicates that the reinforcement effect of FRP reinforcement material makes the strain development of the reinforced beam under tension lag behind that of the non-reinforced beam. This hysteresis is not obvious in the initial stage of loading, and becomes more and more significant as the load increases.

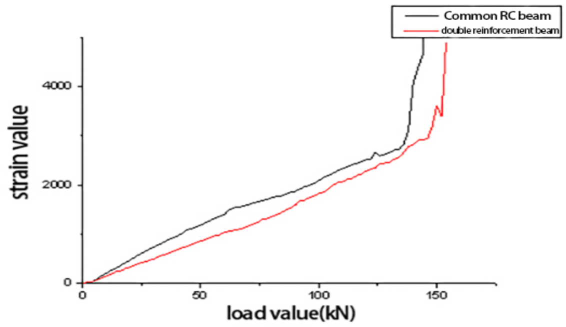


Fig. 7 Common RC beam and reinforced RC beam

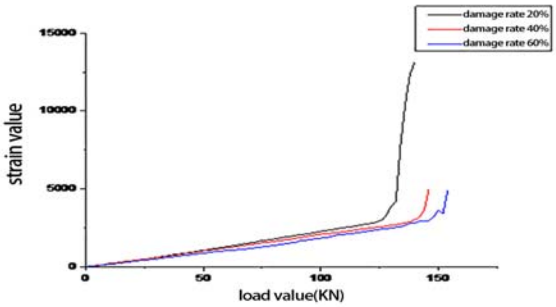


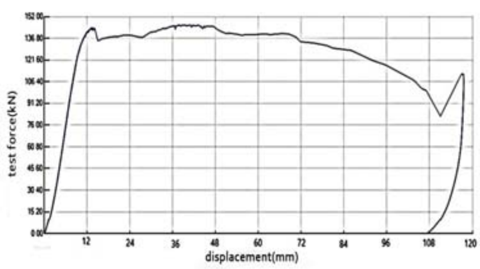
Fig. 8 Load strain curves of different damage rates

3.2 Different damage rate

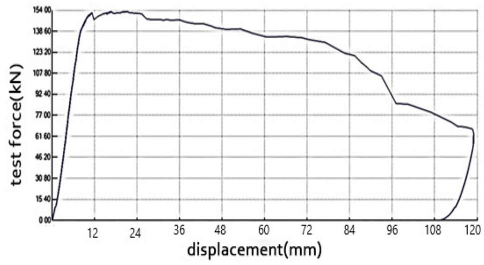
3.2.1 Test result

Cracks appeared in the L3 beam in the early stage. As the load increases, the width of the crack becomes larger, and the anchoring part has obvious noise, and the carbon plate peels and breaks when it is damaged; the overall experimental phenomenon of L4 and L5 is basically the same as that of L3, but we can clearly know from the phenomenon, the L4 beam and the carbon plate are better bonded, and the optimal material utilization rate is achieved.

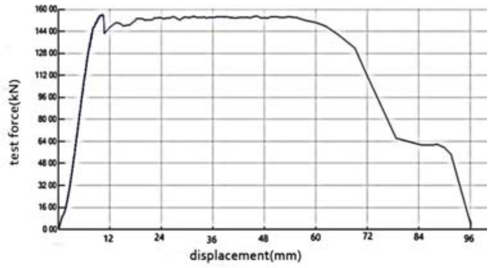
3.2.2 Mid-span deflection



(1) RC beam with 20% anchoring damaged



(2) RC beam with 40% anchoring damaged



(3) RC beam with 60% anchoring damaged

Fig. 9 RC beams with different damage rates

Compared with the displacement-load curves of L3, L4, and L5, the pre-loading curves of L3, L4, and L5 beams are basically the same, the first crack appears at 34 KN, the anchoring part has obvious noise at 108 KN, and the carbon plate peels off at 144 KN; L4 And L5 had the first cracks at 35 KN and 32 KN respectively, and the carbon plate peeled off at 163 KN and 159 KN. Components with different damage rates have little effect on the cracking load, and components with a damage rate of 40% have the largest ultimate load value. As the damage rate increases, the effect of FRP on improving the overall stiffness of the beam is more obvious, and the components with lower damage rate show good plastic properties.

3.2.3 Rebar strain

It can be seen from Figure 8 that at the initial stage of loading, the three curves have almost uniform linear growth, and the difference in damage rate does not affect the reinforcement effect. When the ultimate load is reached, the slope of the member with a damage rate of 20% becomes higher, indicating that the lower the damage rate, the better the ductility performance of the member is restored. As the damage rate increases, the hysteresis of the yield point of the steel bar becomes obvious.

4 Conclusion

(1) Comparing different reinforcement methods, referring to the failure morphology of beams and reinforced beams, it can be seen that the FRP composite anchoring technology effectively prevents the peeling of the FRP board, so that the tensile strength of the FRP board can be fully utilized.

(2) The strengthening effect of FRP slab reinforcement on the flexural bearing capacity of concrete is mainly reflected in the yield of the steel bars.

Compared with non-reinforced beams, reinforced beams have slower mid-span deflection and slower stiffness degradation. After reaching the ultimate load, the mid-span deflection still increased slightly.

(3) The use of steel plates to anchor FRP panels to strengthen the concrete beams can delay the expansion of cracks, make their distribution more even, and significantly increase the cracking load and ultimate load of the concrete beams.

(4) FRP reinforcement material reduces the growth rate of concrete strain and steel bar strain, and the hysteresis phenomenon is not obvious in the initial stage of loading, and becomes more and more significant in the later stage of loading.

(5) For specimens with different damage rates, the member with a damage rate of 40% has the largest ultimate load value.

(6) If the damage on concrete beam with the same reinforcement method and the same materials is too large, its ductility will be affected.

Acknowledgments

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