Finite Element Analysis on Reinforced Concrete Beams Strengthened with CFRP

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Abstract. Reinforced concrete structure is widely used in building structure because of its unique physical and mechanic properties, but with the increase of service life, there will be different degrees of damage in the structures. In this paper, combined with the test beam, a model of reinforced concrete beam strengthened with CFRP is established by using ANSYS finite element software, nonlinear finite element analysis is carried out on the whole process of yield, cracking and destruction of the test beam under secondary load, while different working states of CFRP sheets were simulated by the life and death unit. The results show that the bending performance of reinforced concrete (RC) beams strengthened with CFRP can be predicted by selecting the finite element analysis model rationally.

1. Introduction
The technology of strengthening concrete beams with CFRP sheets is widely used at home and abroad in recent years.[1-2] In theory, sufficient strain is needed to exert the strong tensile properties of CFRP, as a brittle material, the strain range of concrete is very limited, so the effect and ultimate bearing capacity of CFRP reinforced concrete, especially considering the secondary load, has been the focus of attention and discussion in this field.[3-5] However, the structures that need to be strengthened in the actual engineering are those of the existing engineering with insufficient bearing capacity and other conditions, so an analysis on the strengthening of RC beams under secondary load is necessary. In this paper, the finite element analysis software ANSYS is used to simulate 3 test beams, the finite element analysis values and the test values are compared, the results show that they are in good agreement with each other. It is a feasible method to simulate CFRP reinforced concrete beams.

2. Profile of Model Beam
According to the Code for Design of Concrete Structures (GB 50010-2010), three beams of the same size (the sectional size was 120 mm × 250 mm, and the length was 2500 mm) were designed fabricated, as shown in figure 1. In this experiment, unreinforced beam B1 is taken as control beam, the mechanical properties of intact reinforced concrete (RC) beam B2 and the secondary load beam B3 with a load of 0.6Py were studied. Parameters such as the amount of CFRP and the sustained load point of each specimen are shown in table 1. The main experimental results are shown in table 2.
Table 1. Specimen parameters.

| Specimen No. | Ratio of longitudinal reinforcement | Amount of CFRP (Sheets) | Sustained load point | Remark            |
|--------------|------------------------------------|-------------------------|---------------------|-------------------|
| B1           | 1.52%                              | 0                       | —                   | Not strengthened  |
| B2           | 1.52%                              | 1                       | —                   | Intact beam       |
| B3           | 1.52%                              | 1                       | 0.6\(P_y\)         | Resin beam        |

Table 2. Main experimental results.

| Specimens | Load (kN) | Deflection (mm) | Rigidity (N/mm, ×10^4) | Failure modes                          |
|-----------|-----------|-----------------|-------------------------|----------------------------------------|
|           | \(P_{cr}\) | \(P_y\) | \(P_u\) | \(\alpha\) | \(\gamma\) | \(u\) | \(B_{cr}\) | \(B_y\) | \(B_u\) |                                      |
| B1        | 10.0      | 65.2            | 68.7                    | 1.0 | 7.6 | 17.2 | 0.971 | 0.840 | 0.037 | Bending failure, concrete compression failure |
| B2        | 10.1      | 73.0            | 82.4                    | 0.8 | 7.9 | 21.0 | 1.217 | 0.887 | 0.072 | Protective layer in the bending segment peeled off |
| B3        | 12.1      | 80.1            | 92.1                    | 0.7 | 7.3 | 23.7 | 1.862 | 1.026 | 0.073 | CFRP 30% tensile failure, concrete compression failure |

The experimental results show that the reinforcement technology of using CFRP to improve the bearing capacity of RC beams is effective, and the ultimate bearing capacity of the beam strengthened with CFRP sheets was greatly improved. The ultimate state of the RC beams strengthened with CFRP sheets was delayed under a certain load (such as 0.6\(P_y\)). The rigidity of the RC beams strengthened with CFRP was significantly improved, compared with the ordinary RC beams, and the CFRP sheets could improve the rigidity and control the deflection of the components mainly resistant to bending.

3. Finite Element Analysis

3.1. Analysis Model
In this paper, the FEA software ANSYS is used to analyse the whole process of RC beams strengthened with CFRP, and the analytical beam model and material properties are the same as the test definition. The control beam B1 and the test beams B2 and B3 with one CFRP sheet are analysed. In the analysis, concrete is simulated by SOLID65 of 3D 8-node 6-hedron, and the stirrup is realized by the integral model, also called smeared element, which is directly defined by real number in SOLID65. Its advantage is that the modelling is simple, but the internal force of reinforcement cannot be obtained. A separate model LINK8 is used to simulate the tension and compression reinforcement for two reasons. The two reasons are: 1) they are not evenly distributed in the simple girder, if the integral model is used, it does not accord with the actual situation. 2) The strain value of the tensile steel bar needs to be read to investigate the structural performance of the beam in detail. CFRP is a material with only intra-plane stress and minimal external stiffness, and ANSYS provides SHELL41 element for simulation.
3.2. The Life and Death Unit Simulates Different Working States

In the practical application of CFRP reinforcement, due to various limitations, the load can’t be completely removed before the reinforcement. CFRP is usually directly pasted on the surface of the member without unloading, so that the initial strain of CFRP is 0, and the initial working stress of CFRP is also 0. CFRP can only play a role with the further development of the deformation of the strengthened member, which is the so-called "secondary load" problem. ANSYS requires that the model must be built all at once in the front processor. Therefore, in the first load step, the unit life and death technology is used to kill all Shell41 units and then apply the load, which is equivalent to the component working without reinforcement. These units will be activated after the predetermined load is applied, so as to simulate the secondary load problem while the Shell41 units are never killed can simulate intact reinforced beam.

3.3. Compare with the Test Results

The comparison of ANSYS finite element analysis and test results are shown in figure 2 (a, b, c) which is about control beam B1, intact strengthened beam B2 and secondary load strengthened beam B3. The FEA results are consistent with the test results to a certain extent. Because of the difference between the constitutive relation used in the model and the actual test, the horizontal section in the test curve could not be clearly simulated. Figure 2 (b) shows that before B2 enters the yield stage of reinforcement, ANSYS finite element analysis can simulate the load-deflection curve of concrete beam very well. When the longitudinal reinforcement reaches yield, the bearing capacity of the test beam is slightly better than that of the finite element model. Since B3 is strengthened with CFRP sheets under a certain load point (such as 0.6\(P_y\)), Figure 2(c) shows that there is a certain difference between the test value and the analysis value, which is related to the difference between the material constitutive relation used in the model and the actual specimen, and these issues need further study.

The comparison of analysis values of load deflection curves of the three test beams is shown in figure 3. There is no significant difference between B1, B2 and B3 at the initial loading stage, when the load is increased to the holding point, the load deflection curves of B2 and B3 are separated. Under the same external force, the deflection of B2 is greater than that of B3, for B3 is strengthened when certain damage occurs to the member. In this way, the tensile properties of CFRP can be fully utilized and the ultimate bearing capacity of the member can be improved.

![Comparison of load-deflection curves of B1 beam](image-url)
(b) Comparison of load-deflection curves of B2 beam

(c) Comparison of load-deflection curves of B3 beam

Figure 2. Comparison of Load-Deflection curve.

Figure 3. B1, B2 and B3 Load-Deflection curve.
4. Conclusion
In this paper, an experimental study of one control beam and two test beams pasted with one CFRP sheets is carried out and compared with the finite element analysis. From the comparison results, the two fit very well. The finite element analysis can save the test fund, and it is worth promoting in this field. The ultimate bearing capacity of strengthened beams under secondary load is higher than that of intact strengthened beams. Which indicates that the strengthened beams under secondary load can exert the strong tensile resistance of CFRP and conform to the engineering practice. In the finite element analysis, the life and death element is used to simulate the strengthened beams under secondary load. The analysis results agree well with the test results, which illustrates that the life and death technology is feasible.

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