Research on Continuous Concrete Continuous Beam with BFRP on FEM

Changyi Yu1,2,3,4*
1CCCC-Tianjin Port Engineering Institute, Ltd., Tianjin 300222, China
2CCCC First Harbor Engineering Company, Ltd., Tianjin 300461, China
3Key Laboratory of Geotechnical Engineering, Ministry of Communications, Tianjin 300222, China
4Key Laboratory of Geotechnical Engineering of Tianjin, Tianjin 300222, China;
* Corresponding author’s e-mail: yu_longone@163.com

Abstract. At present, the research on basalt fibre reinforced polymer (BFRP) at home and abroad is still in the initial stage, and the research on strengthening beams mostly focuses on strengthening simply supported beams, while the research on strengthening reinforced concrete continuous beams with BFRP is still rare. In this paper, the finite element method is used to simulate the reinforced concrete continuous beam strengthened with BFRP, and the results of cracking load, ultimate load, stiffness and deflection are obtained. The results show that ABAQUS can simulate the relevant mechanical properties of the strengthened beam. It provides effective guidance for the design and application of reinforced concrete continuous beam strengthened with BFRP.

1. Introduction
BFRP, as a new type of fiber material, is another mature fiber material suitable for civil engineering after carbon fiber and glass fiber [1]. BFRP has good extensibility, high temperature resistance, corrosion resistance and low price, and is becoming a new darling in the field of fiber reinforcement[2]. The concrete cracking load and ultimate bearing capacity of reinforced concrete beams strengthened with BFRP have been improved to varying degrees. However, the ductility of the members will also decrease correspondingly, and the BFRP will break suddenly after the steel bar in the tensile area of the test specimen reaches the yield load, resulting in obvious brittle failure of the strengthened specimen [3]. The ultimate failure form of the strengthened beam is that the BFRP is stripped and loses its shear bearing capacity, resulting in rapid shear and compression failure of the beam. And this kind of failure is an unanticipated brittle failure.

The mechanical properties of reinforced concrete beams strengthened with BFRP were tested, and the failure process, stress distribution, bearing capacity and ductility of the beams were observed and analysed [4]. It is concluded that when the number of BFRP layers is small, the bearing capacity increases greatly, and the use of BFRP also increases the flexural rigidity of members.

The research direction of strengthening reinforced concrete beam structure with BFRP is mainly focused on simply supported beams, while continuous beams are widely used in actual projects. In the completed research of strengthening reinforced concrete continuous beams with BFRP, the research on the mechanical properties of reinforced concrete continuous beams is still relatively few. Therefore,
it is necessary to study the mechanical properties of reinforced concrete continuous beams strengthened with BFRP, and it will play a great guiding role in practical engineering.

2. Theory
After bonding BFRP, the cross-sectional strain of the beam is linearly distributed. Although the assumption of flat section is not applicable in special sections such as cracked section, it is still applicable in pure bending area.

In the early design of the members, the ultimate bearing capacity and ultimate bending moment of the reinforced structure should be determined so as to select the required loading equipment and loading scheme. According to the relevant theory of reinforced concrete, when the tensile stress of the reinforcement in the tension zone of the normal section reaches the yield strength, the concrete in the compression zone also reaches the ultimate compressive strength, and the BFRP reaches the ultimate tensile strength [5-6]. The ratio of the height of the compression zone to the height of the section is expressed as $\xi_{cb}$:

$$\xi_{cb} = \frac{x_i}{h} = 0.8 \frac{c}{h} = 0.8 \frac{\varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_{fu}}$$

Where: $x_i$ the height of the compression zone at the time of failure, $\varepsilon_{cu}$ the compressive strain of concrete and $\varepsilon_{fu}$ the strain of basalt fiber. X represents the height of the compression zone when the concrete reaches,

The tensile stress $\sigma_{bf}$ of BFRP is the product of the tensile strain $\varepsilon_{bf}$ of BFRP and its elastic modulus $E_{bf}$, $\sigma_{bf} = E_{bf} \varepsilon_{bf}$

1)When the height $x$ of the concrete compression zone meets $\xi_{\text{job}} < x < \xi_{\text{b}}$,

$$M_0 \leq f_c b x (h_0 - \frac{x}{2}) + f_y A_s (h_0 - a) + E_{bf} \varepsilon_{bf} A_{bf} (h - h_0)$$

2)When the height $x$ of the concrete compression zone meets $x \leq \xi_{\text{job}} h$

$$M_0 \leq f_y A_s (h_0 - 0.5 \xi_{\text{job}} h) + E_{bf} \varepsilon_{bf} A_{bf} (h (1 - 0.5 \xi_{\text{job}}))$$

3)When the height of the concrete compression zone meets

$$M_0 \leq f_y A_s (h_0 - a) + E_{bf} \varepsilon_{bf} A_{bf} (h - a)$$

The height $x$ of concrete compression zone and BFRP strain $\varepsilon_{bf}$ are calculated by the following formula:

$$f_c b x = f_y A_s - f_y A_s + E_{bf} \varepsilon_{bf} A_{bf}$$

$$x = \frac{0.8 \varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_{fu}} h$$

Where, $M_0$ the bending moment of mid-span section when a single span is used as a simply supported beam; $A_s$, $A_s$, tensile steel cross-sectional area, compressive steel cross-sectional area; $f_y$, $f_y$ tensile strength of tensile reinforcement and compressive strength of compressive reinforcement; $A_{bf}$, $E_{bf}$ BFRP cross-sectional area, BFRP elastic modulus; $f_c$ Axial compressive strength of concrete; $b$, $h$, $h_0$ Section width, height and effective height;
Ultimate compressive strain of concrete; $\varepsilon_{\text{cu}}$; BFRP allows tensile strain; $\varepsilon_1$ - Initial strain; $\varepsilon_{\text{cf}}$ BFRP reaches the allowable tensile strain and the limit when the concrete compression zone is damaged is relative to the height of the compression zone, $\varepsilon_f = \frac{0.8\varepsilon_{\text{cu}}}{\varepsilon_{\text{cu}} + [\varepsilon_{\text{cf}}] + \varepsilon_1}$

3. Finite element model

Due to the limited test conditions, it is one of the most effective means to simulate the members by using finite element software in order to obtain more mechanical properties and analysis data of reinforced concrete continuous beams strengthened with BFRP. In the process of establishing the finite element model, the relevant data parameters used in the test can be selected to establish the finite element analysis model, and the relevant mechanical properties of such structures can be comprehensively calculated and analyzed.

Based on the experimental data, this paper uses ABAQUS finite element software to establish a reinforced concrete continuous beam model strengthened with BFRP, and uses finite element method to analyze the model.

The section size of the continuous beam is 4000mm, the concrete strength grade is C30, HRB335 is used for longitudinal tensile and compressive reinforcement, and HPB235 is used for stirrups. The model is shown in Figure 1.

![Figure 1. Reinforced concrete model](image)

The red part in Figure 1 is the steel bar, and the steel bar is an elastic model in the model. In Figure 2, the pink part is the reinforced position of BFRP. In the simulation process, different models have different layers of reinforcement.

![Figure 2. Constraints of BFRP and concrete](image)

Figure 3 shows the loading model of the continuous beam, with three simple supports at the bottom and two loading points at the top. The model adopts displacement control loading method, and the loading process adopts linear loading.

![Figure 3. Support and Load Point Constraints](image)

4. Model analysis

By comparing the model Miss stress cloud picture simulated by ABAQUS software, it can be seen that the stress at the negative bending moment of the support in the continuous beam is the largest. This shows that in the reinforcement design of the continuous beam, attention should be paid to the weak negative bending moment of the intermediate support.

An important indicator of structural stiffness is the deflection value, and a larger deflection indicates that the structural stiffness is smaller. Compared with the structure shown in Figure 7, it can be seen that under the same ultimate load state, the deflection of the basalt reinforced beam is smaller,
and the results show that the rigidity of the continuous beam strengthened with BFRP has been strengthened.

Figure 4. Test beam Miss cloud.

Figure 5. Miss cloud picture of BFRP at negative bending moment.

Figure 6. Nephogram of mid-span BFRP Miss.

Figure 7. Comparison of reinforcement effect of BFRP.

5. Conclusion

After strengthening with BFRP, the stiffness of the strengthened beam has been significantly improved, and the deflection of the strengthened beam is less than that of the unreinforced beam. And with the increase of the number of layers of BFRP, the deflection value increases more obviously. The average strain of reinforced concrete continuous beams strengthened with BFRP is in line with the flat section assumption, which shows that the flat section assumption is still applicable to reinforced concrete continuous beams strengthened with BFRP. The interfacial shear stress between BFRP and concrete is large, so the bonding method of BFRP should be further improved in actual construction. ABAQUS software for numerical simulation of reinforced concrete continuous beam strengthened with BFRP can still truly reflect the data of each stress state.

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