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Enhancement of Cantilever Beams with Fibre-Reinforcement Plastic

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This paper aims to design a feasible procedure of fibre-reinforcement plastic (FRP) enhancement. To this end, the author reviewed the development history of the FRP, and summarized the two common methods of FRP enhancement, namely, the embedded FRP enhancement and external bonding. Based on these methods, an FRP enhancement plan was developed for enhancing the cantilever beams of a balcony in Daqing, China. The mathematical calculations and enhancement steps of the plan were introduced in great details. The case study proves that FRP materials can prolong the service life of concrete structures and reduce the engineering cost. The research findings shed new light on the application of the FRP in the engineering field.

1. Introduction

Over the years, universities, research institutes and material manufacturers have devoted great efforts to producing fibre materials that can perfectly reinforce the concrete structure (Jiang et al., 2004). In the 1980s, their efforts eventually paid off with the successful synthesis of fibre-reinforcement plastic (FRP) in Germany and Switzerland. The FRP reinforcement is known for its good performance, sound durability and high efficiency. Over the years, the technology has spread from Europe to the whole world.
The FRP is a composite material made of a resin matrix reinforced with high-strength and high-modulus fibres. The bundle structure endows the material with good corrosion resistance and tensile strength despite the lightweight. The most popular FRP materials include glass fibre, carbon fibre and aramid fibre. Figure 1 compares the mechanical performance of the FRP with other common fibre materials.

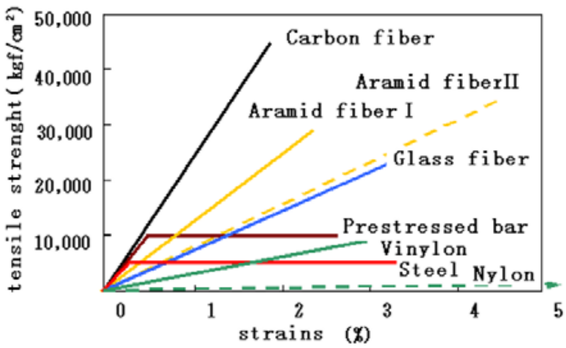

Figure 1: Mechanical performance comparison of FRP with other fibre materials

2. FRP Reinforcement

2.1 Embedded FRP reinforcement

Recent years saw the combination of the FRP and the embedded reinforcement technique. The resulting embedded FRP reinforcement is a very promising method for concrete enhancement. By this method, a

groove is carved on the surface of a concrete component, and filled with FRP bars or laths; then, the FRP materials are stick together with the component using adhesive glue. In this way, the component becomes less prone to bending or shearing. The embedded FRP reinforcement is very convenient. It does not require intense labor, heavy machinery or a huge work space (GB50367-2006; CECS 25:90).
For the sake of quality, the embedded FRP reinforcement should be implemented in the following steps: open a groove on the surface of component as per the design; remove the dust and residue from the groove; inject adhesive glue into the groove to half of the depth; place FRP bars or laths into the groove, press lightly, and continue to inject adhesive glue until filling up the groove; polish the surface after the adhesive glue solidifies.

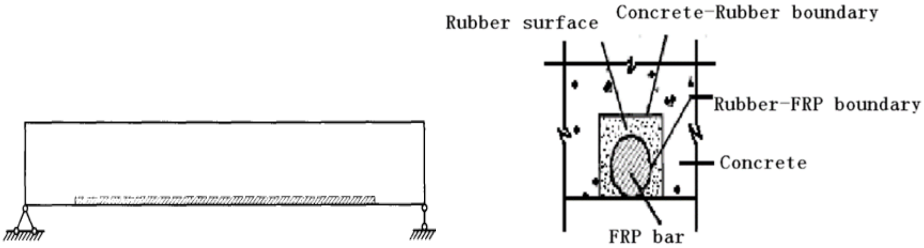

Figure 2: Plan for embedded FRP reinforcement

(1) To slot on the surface structure according to design requirements;
(2) To remove the dust and the residue in the groove;
(3) To inject the binder in the groove to the half height;
(4) To put FRP bar or FRP lath into the groove and to press lightly, and to continue to inject the resin into the groove to the full;
(5) After the binder solidifying, the surface needs to be processed.

2.2 External bonding

Another common FRP reinforcement method is called external bonding. As shown in Figure 3, external bonding refers to pasting fibre cloth or sheet onto the surface of a concrete component using special adhesive glue (Wu et al., 2009). This method was invented in the late 1980s to replace the traditional concrete reinforcement method, which pastes steel plate onto the concrete structure. The external bonding is extremely popular. The FRP material adopted for this method is mainly carbon fibre cloth.
The enforcement effect of external bonding hinges on the quality of the FRP cloth or sheet. To ensure the quality, the external bonding method must be implemented in the five steps: process the base, coat it with rubber, level out the base, attach the FRP cloth or sheet onto the base, and fix the cloth or sheet with adhesive glue.
(1) To process the base;
(2) To coat the bottom rubber;
(3) to level;
(4) to bond;
to protect;

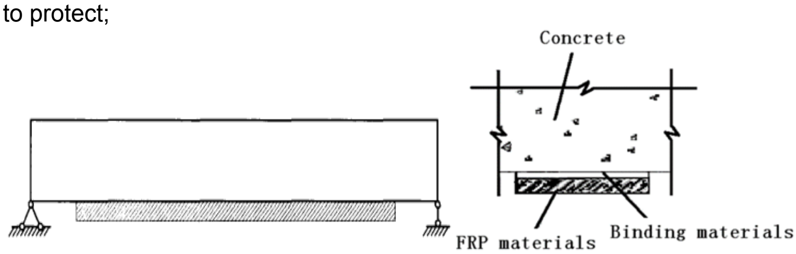

Figure 3: Plan for external bonding

3. Case Study

constructed with bricks. During the construction, it was found that the Φ8” stirrups in the cantilever beams of a balcony could not be elongated to the required length. Considering the structural stress features, the existing steel bars were not enough to prevent the ductile failure of the cantilever beam. Thus, it is necessary to reinforce the stirrups in the cantilever beams.

The reinforcement operation was carried out as follows. Three 100mm-wide ring carbon fibre sheets were pasted at the interval of 250mm on the outer end of each cantilever beam. The sheets were lapped by a length of 150mm at the top of each beam. The carbon fibre sheets are made of 200g/m^2 unidirectional plaid cloth. In addition, a 15mm-deep groove was opened at the four corners of each beam. The other procedures were conducted as per relevant standards. The above operation helped to avoid structural damages induced by ductile failure of the beams.

3.1 Mathematical calculation (Chen et al,2009; Chen et al., 2018; Wang et al.,2009)

(1) The material properties can be calculated as:

$$f_{fu} = C_E f_{fu}^*,\ \varepsilon_{fu} = C_E \varepsilon_{fu}^* \tag{1}$$

(2) The concrete performance, ordinary steel bar properties, and FRP performance can be preliminarily estimated as:

$$E_c = 57{,}000\sqrt{f_c'},\ \rho_s \equiv \frac{A_s}{bd},\ n_s \equiv \frac{E_s}{E_c},\ A_f = nt_f w_f,\ \rho_f \equiv \frac{A_f}{bd},\ n_f \equiv \frac{E_f}{E_c} \tag{2}$$

(3) The strain state at the bottom of each cantilever beam can be determined as:

$$\varepsilon_{bi} = \frac{M_{DL}(h-kd)}{I_{cr}E_c} \tag{3}$$

(4) The bonding coefficient of the FRP material can be identified as:

$$\kappa_m = 1 - \frac{nE_f t_f}{2{,}400{,}000} \tag{4}$$

(5) The height of the neutralization axis C was initially estimated as 0.20d. The value of C can be adjusted again after checking the equilibrium equation.

$$c = 0.20d \tag{5}$$

(6) The strain of the FRP material can be obtained as:

$$\varepsilon_{fe} = 0.003\left(\frac{h-c}{c}\right) - \varepsilon_{bi} \le \kappa_m \varepsilon_{fu} \tag{6}$$

The strain of ordinary steel bar can be calculated by similar triangles:

$$\varepsilon_s = \left(\varepsilon_{fe} + \varepsilon_{bi}\right)\left(\frac{d-c}{h-c}\right) \tag{7}$$

(7) The stresses of ordinary steel bar and the FRP material can be derived as:

$$\mathrm{f}_s = E_s \varepsilon_s \le f_y,\ f_{fe} = E_f \varepsilon_{fe} \tag{8}$$

(8) The internal force can be deduced after checking the equilibrium equation.

$$c = \frac{A_s f_s + A_f f_{fe}}{\gamma f_c' \beta_1 b} \tag{9}$$

(9) The C value can be adjusted to satisfy the equilibrium equation. Then, the cross-sectional flexural strength can be calculated as:

$$\phi M_n = \phi\left[A_s f_s\left(d - \frac{\beta_1 c}{2}\right) + \psi A_f f_{fe}\left(h - \frac{\beta_1 c}{2}\right)\right] \tag{10}$$

(10) The stresses of the ordinary steel bar and the FRP material can be calculated separately. It is found that the stress of the ordinary steel bar is lower than the limit value, and that of the FRP material is below the creep fracture stress.

$$k = \sqrt{\left(\rho_s n_s + \rho_f n_f\right)^2 + 2\left(\rho_s n_s + \rho_f n_f\left(\frac{h}{d}\right)\right)} - \left(\rho_s n_s + \rho_f n_f\right)$$

$$f_{s,s} = \frac{\left[M_s + \varepsilon_{bi} A_f E_f \left(h - {kd}/{3}\right)\right]\left(d - kd\right) E_s}{A_s E_s \left(d - {kd}/{3}\right)\left(d - kd\right) + A_f E_f \left(h - {kd}/{3}\right)\left(h - kd\right)} \quad (11)$$

$$f_{s,s} \le 0.80\, f_y, \quad f_{f,s} = f_{s,s}\left(\frac{E_f}{E_s}\right)\left(\frac{h - kd}{d - kd}\right) - \varepsilon_{bi} E_f, \quad F_{f,s} = 0.55 f_{fu}$$

3.2 Reinforcement procedure

The cantilever beams were reinforced through the following steps (Zhang et al., 2011): determining the reinforcement position, basic levelling, preparing for the application of adhesive glue, cutting carbon fibre cloth, pasting carbon fibre sheets, and further protection.

3.3 Concrete construction methods and construction measures

(1) Determining the reinforcement position:
According to the design, the objects to be reinforced are several cantilever beams of a balcony in the construction site (Wang et al., 2017). As mentioned before, three 100mm-wide ring carbon fibre sheets were pasted at the interval of 250mm on the outer end of each cantilever beam. If the carbon fibre sheets could not form a ring, they were grinded into 100×700mm strips at the bottom of the beam and pasted in two layers to guarantee the reinforcement quality (Chen et al., 2017).
(2) Basic levelling:
A 15mm-deep groove was ground by an angle grinder at the four corners of each cantilever beam. The dust and loose materials on the concrete surface were removed by a brush or a dryer, and the surface was kept dry. Then, the concrete surface was wiped again using cotton yarn with acetone or alcohol, aiming to eliminate organic matters from the surface (Xia et al., 2017).
(3) Preparing for the application of adhesive glue
Before applying the glue, it is necessary to check the construction environment. The base to be pasted must be free of condensation of water vapour. Otherwise, it would be difficult for the adhesive glue to solidify, not to mention achieving a desirable adhesive effect (Raafat et al., 2013).
The adhesive glue was a mixture of two materials, denoted as A and B. The two materials were mixed together according to instructions and stirred carefully until the colour of the mixture became evenly distributed. During the glue preparation process, the container was kept clean and free of oil, and no water was allowed to enter the container. The prepared glue was then applied to the base with a brush.
(4) Cutting carbon fibre cloth
The carbon fibre cloth was cut into required pieces by scissor or a sharp knife. The resulting carbon fibre sheets were rolled by a roller to prevent folding.
(5) Pasting carbon fibre sheets

Figure 4: Concrete beams before enhancement

Figure 5: Preparations for the enhancement

Figure 6: Plan for field enhancement

Figure 7: Concrete beams after enhancement

When the glue on the bottom was about to dry after one hour of drying, the carbon fibre sheets were dipped in the adhesive glue, and then pasted into a ring, forming a closed hoop (Zheng et al., 2016). If the carbon fibre sheets could not form a ring, they were pasted into a U-shaped hoop at the bottom of the beam (Gao et al., 2015). Then, the carbon fibre sheets were rolled over by a plastic roller along the direction of carbon fibres until the sheets were saturated by the glue. After that, the surface of the carbon fibre sheets was coated with another layer of glue (Guan et al., 2013).

(6) Further protection

After pasting the carbon fibre sheets, a layer of dry sand was immediately casted onto the sheets if plastering protection was required (Oral et al., 2004).

4. Conclusion

In order to create a feasible procedure of fibre-reinforcement plastic (FRP) enhancement, this paper reviews the development history of the FRP, and introduces two common methods of FRP enhancement: the embedded FRP enhancement and external bonding. Inspired by these methods, the author put forward an FRP enhancement plan for the cantilever beams of a balcony in Daqing, China, and detailed the mathematical calculations and enhancement steps of the plan. Through the case study, it is proved that FRP materials can prolong the service life of concrete structures and reduce the engineering cost. The research findings shed new light on the application of the FRP in the engineering field.

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