A Proposed Method of FRP Anchorage for FRP Confined Over-Reinforced Concrete Beam

Nuroji, Ay Lie Han, Sri Tudjono, Lena Tri Lestari, and Tiara Murtisari

Abstract Fiber Reinforced Polymer (FRP) is a material for strengthening, retrofitting or confining concrete elements. Research on the FRP performance demonstrated that debonding was one of the major failure modes, reducing the ultimate capacity of the composite action between the FRP and concrete. Debonding between FRP and concrete is mostly characterized in the interfacial transition zone (ITZ). Increasing the bond performance in the ITZ is conducted by applying an anchorage system to prevent premature bond loss. The aim of this paper is to propose three concepts of FRP anchorage systems and evaluate their usefulness and theoretical effectiveness. For evaluation, an over-reinforced flexural member is externally strengthened using carbon fiber wraps, the compression area of this member is confined using a u-shape configuration. The three types of FRP anchorages introduced in this study are the spike, insertion, and stitch anchor. It is expected that the anchors will increase the bond performance between the concrete and the CFRP, preventing premature failure and increasing the concrete strength and deformation behavior due to the confinement effect. At further stages, full size elements will be tested to prove this hypothesis, and to evaluate which type of the three anchors is the most effective.

Keywords Fiber-reinforced polymer · Anchorage · Confinement

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1 Introduction

Improving and strengthening of existing structural elements in the field are often needed as a result of additional building loads in the form of live, dead, or earthquake loads. The use of Fiber Reinforced Polymers (FRP) for the external reinforcement of structural elements is one method that is being researched extensively, since the FRP has a very high tensile strength exceeding the tensile strength of commonly reinforcing steel [1]. Further, the composite action between the FRP and concrete provides an excellent compatibility behavior in transferring both stress and strain between the two materials. FRP can be used to increase the shear [2–6], the bending and the concrete strength due to the confinement effect [7–15] of a concrete element, leading in an overall enhancement of the member. One of the problems in related prior studies was that the beam failed before the FRP reached its maximum strength due to debonding [16]. Previous studies have found that FRP sheets are debonding by average of 50% of their tensile capacity. Therefore, additional anchorage systems are required to improve the bond behavior in the interfacial transition zone (ITZ) [17–22]. Anchorage system for externally bounded FRP aims to: (I) prevent or delay interfacial crack opening; (II) increase the total available interfacial shear stress transfer; and (III) to provide a stress mechanism where no bond length is available beyond the critical section [18, 23]. The effectiveness of CFRP wraps can be improved by applying multiple layers of wraps [24], but this method will not increase the bond capacity between the wraps and the concrete.

The effective strain of the FRP reinforcement must be limited by the debonding strain, εfd, to avoid cracking due to debonding failure (Eq. 1) [25].

$$\varepsilon fd = 0.41 fc'nEft \leq 0.9\varepsilon fu \tag{1}$$

where f_c', n, Ef, tf, and εfu are concrete compression strength, number of FRP layers, elastic modulus tensile of FRP, thickness of FRP for each layer, and ultimate strain of FRP, respectively. Several studies have shown that anchorage FRP is viable method to delay or prevent FRP debonding to concrete [19, 23, 26, 27].

In the research conducted by [3, 16, 28], experimental testing was carried out on over-reinforced beams that were reinforced more with external FRP reinforcement, but debonding occurred in the stress area due to the beam bending response followed by the shear strain between the concrete and FRP. The members were utilized with u-wraps in the compression zone of the member. U-wraps are commonly used for shear reinforcement of flexural elements [3, 29–32].

2 Concept and Method

2.1 Specimen and Anchorage Details

Figure 1 shows a CFRP wrap-confined beam without anchorage. Three types of FRP anchorage used in this study are shown in Fig. 2.

Over-reinforced beams are used to obtain a wide compressive area of the beam. CFRP Wrap is installed in the stressed area of the beam and a U-shape is used to consider that the FRP cannot be wrapped completely due to the presence of a slab at the existing structure.

In this study, three types of FRP anchor are introduced, they are spike, insertion, and stitch. Anchors will improve the strength of the far end fibers of the FRP, and directly prevent the shear-bond strains to increase [2, 33–37]. The spike anchor is made of CFRP string which is partially hooked into the concrete cover and the rest is fan-shaped spread over the surface of CFRP wrap (Fig. 2a). This anchor model uses the model proposed by researchers and proven highly effective [19, 20, 38, 39] with slight adjustments to the beam dimensions used in this study. Another method of anchoring is an insertion (Fig. 2b), the CFRP wrap edge is inserted into the concrete cover opening and filled with epoxy. The opening groove is curved to avoid the CFRP wrap being torn at the outside corner of the opening due to a stress concentration. In the stitch anchor, CFRP string [4, 40] is used which is formed as shown in Fig. 2c.

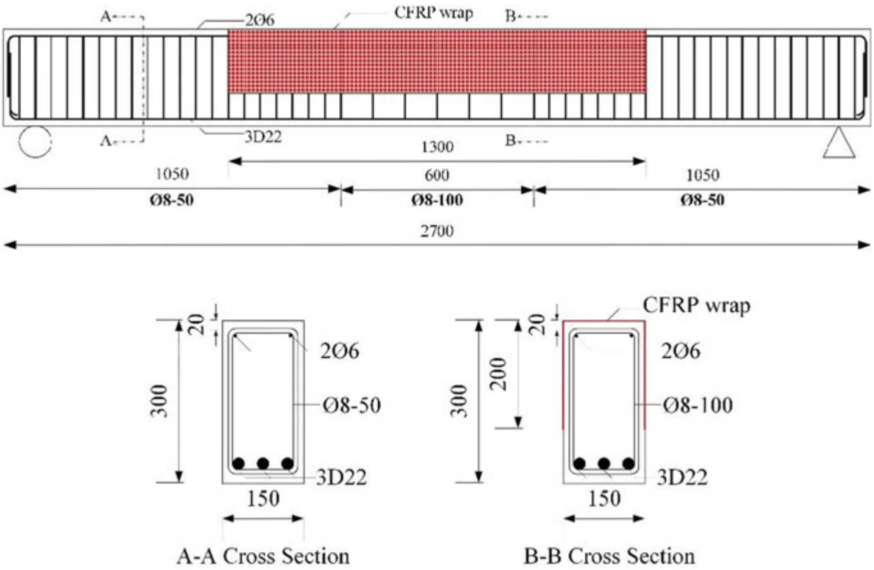

Fig. 1 CFRP wrap-confined beam without anchor

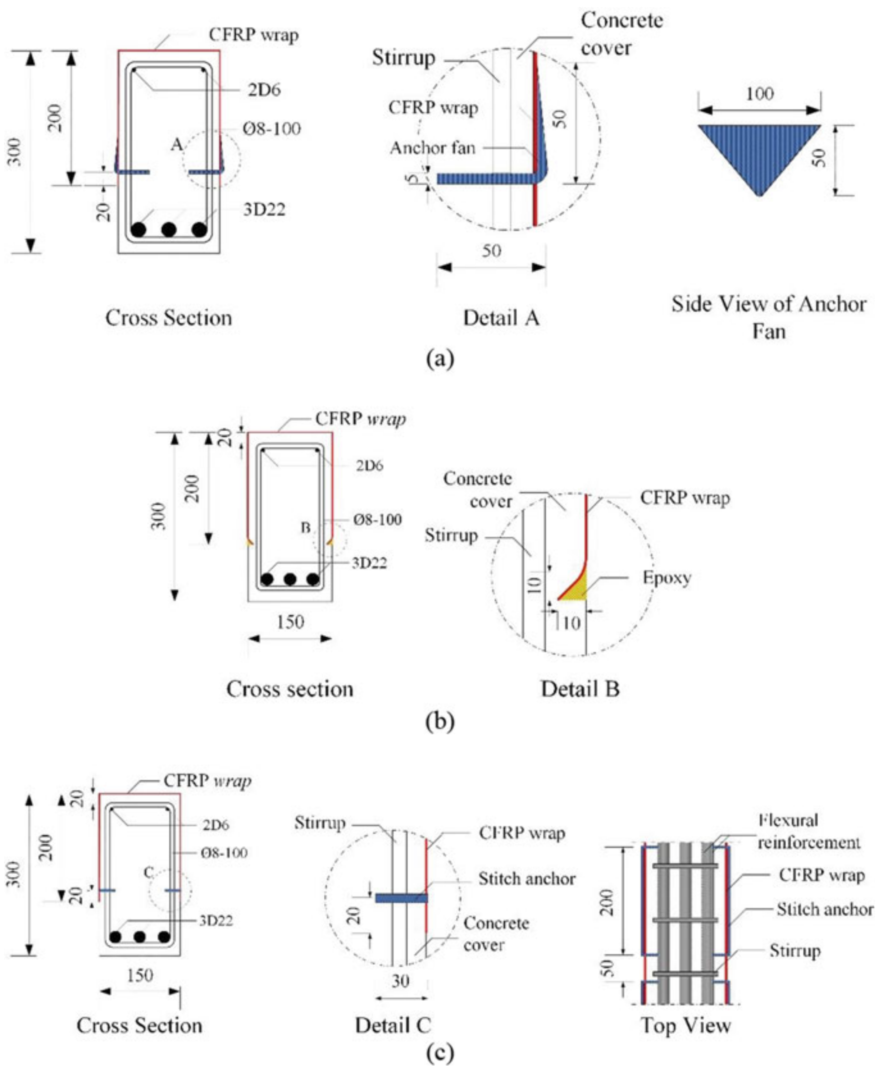

Fig. 2 Variety of FRP anchorage **a** Spike **b** Insertion **c** Stitch

The concrete is perforated using a drill then the anchor stitch is inserted and glued using epoxy.

2.2 Experimental Test Set-Up

The test will be carried out when the concrete reaches 28 days with a 2-point-load system (Fig. 3). The two-point loading system is used so that at middle span of the beam, pure bending occurs without any shear intervention. The FRP is installed 200 mm over the load point to avoid excessive stresses on the ends of the CFRP wrap. The compression strain gauge is installed horizontally and transversally for both concrete and FRP to assess the confinement. Strain gauge for steel is only installed on the tensile reinforcement due to the impossibility to be attached on small diameter compression reinforcement. In order to obtain beam deflection and curvature, one LVDT is installed at the middle of the beam span and two LVDT with a yoke for each other are installed next to it.

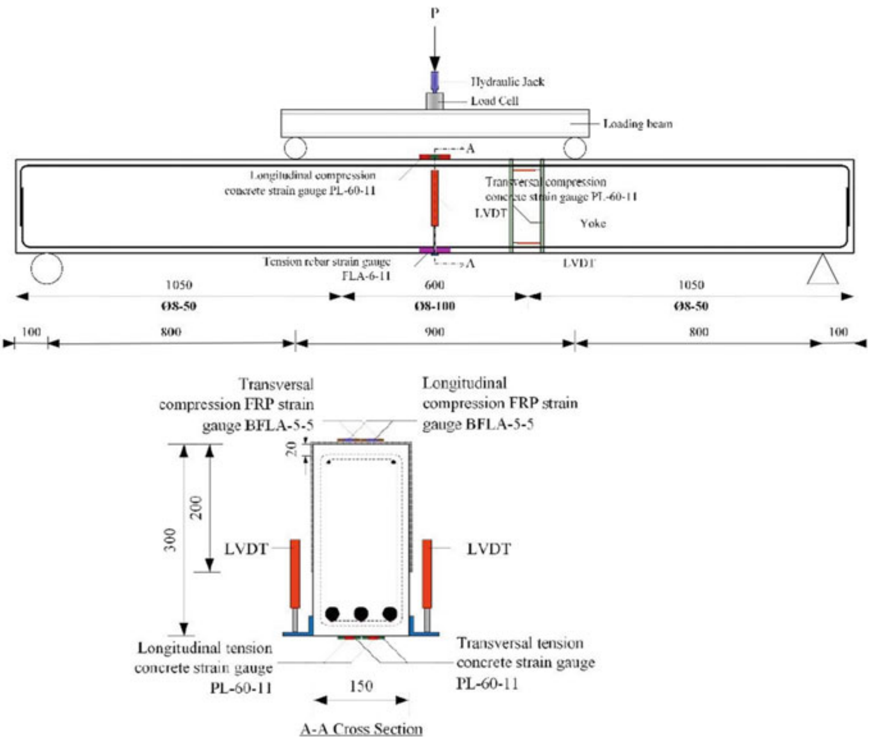

Fig. 3 Setup of testing

3 Discussion

The three types of FRP anchors are expected to be able to overcome debonding by providing confinement to the compressed concrete region of the beam. In over-reinforced beams, failure will occur due to the maximum compressive strain of the concrete before the reinforcing steel yields. As a result of FRP anchor, U-shaped FRP can hold the compressive stress after maximum compressive strain of concrete is reached so that the ultimate load increases until the tensile reinforcement yields. FRP anchorage has a role to anticipate U-shaped FRP debonding phenomenon which is caused by shear stress along the interface of U-shaped FRP and concrete. For spike and stitch anchor, the anchor space/distance is important to make sure the anchors work fine and do not lead stress concentration around the anchor hook. By comparing the three types of FRP anchors, it can be seen which types of anchoring are more effective to use in beam reinforcement using FRP.

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