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Flexural behavior of RC beams strengthened by NSM GFRP Bars having different end conditions

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ABSTRACT

Near surface mounted (NSM) fiber reinforced polymer (FRP) bars became more effective in strengthening reinforced concrete (RC) beams. This is because it increases the bond capacity and makes a protection against external damage. Most of previous related researches stated that the failure of the tested RC strengthened beams with NSM FRP is due to debonding or concrete cover separation. In this research the ends of the NSM glass fiber reinforced polymer (GFRP) bars were bent to delay or prevent NSM FRP debonding and concrete cover separation and thus increasing the load carrying capacity of the strengthened beams. The inclination angles of GFRP bars with bent ends were 90° and 45°. Straight GFRP bars with variable lengths were also used for comparison. The test results demonstrated that the GFRP bars with bent ends prevented the concrete cover separation and increased the load carrying capacity of the strengthened beams. The load carrying capacity of the strengthened beams by straight NSM bars and those having 45° and 90° inclined ends were 177%, 201%, and 185% of that of their control beam, respectively.

1. Introduction

Externally Bonded (EB) and near surface mounted (NSM) are the most commonly strengthening methods. In these two methods, Fiber Reinforced Polymer (FRP) reinforcements were used to upgrade reinforced concrete (RC) members. Externally bonded technique using FRP bars had been widely used for strengthening RC members. This is due to many advantages of FRP bars such as high strength to weight ratio, easy installation and high resistance to corrosion. Although the use of EB technique increases the load carrying capacity of the RC strengthened members, the NSM FRP strengthening technique offers many advantages over EB. These advantages include increasing bond capacity due to larger bonded surface area and make a protection against external damage results from external impacts, since the bar is embedded in the concrete cover [1,2]. Although the researches indicated that the EB and NSM techniques are effective techniques for increasing both flexural and shear capacity of structural members [3–6], the failure due to debonding of FRP reinforcement is still the most common failure mode [7–10].

Debonding may occur as: a concrete cover separation or end bar debonding [11]. Debonding failure of NSM FRP is interfacial debonding at the FRP–epoxy interface [12]. The failure of NSM FRP structural elements may occur due to splitting of the epoxy cover, cracking of the concrete surrounding the groove and pullout of the FRP bars or combined failure [13–24]. Although debonding failure is less expected to happen in NSM FRP reinforcement compared to EB FRP sheets [25], previous researches reported that, NSM FRP reinforcements cannot reach their full tensile strength, due to premature debonding or epoxy and concrete splitting [13–15]. Because of the debonding problem, researches were devoted to find the way by which such type of failure can be prevented. Hybrid bonded FRP technique [26] and U-anchor system [27] are suggested to prevent such type of failure. Sallam et al. [2] found that cover separation or debonding failure in EB system can be prevented by concrete cover replacement technique. Moreover, external stirrups and U-wraps were used to prevent cover separation or FRP debonding in EB or NSM strengthened beams [28]. It was concluded that [28] the use of external transverse anchoring reinforcement increased the flexural capacity of the strengthened members.

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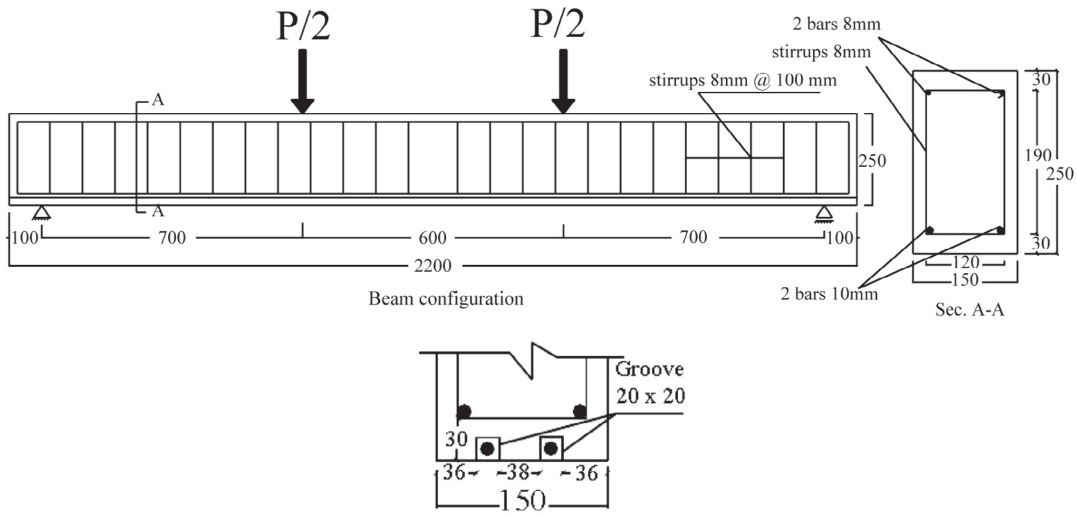

Fig. 1. Beam details.

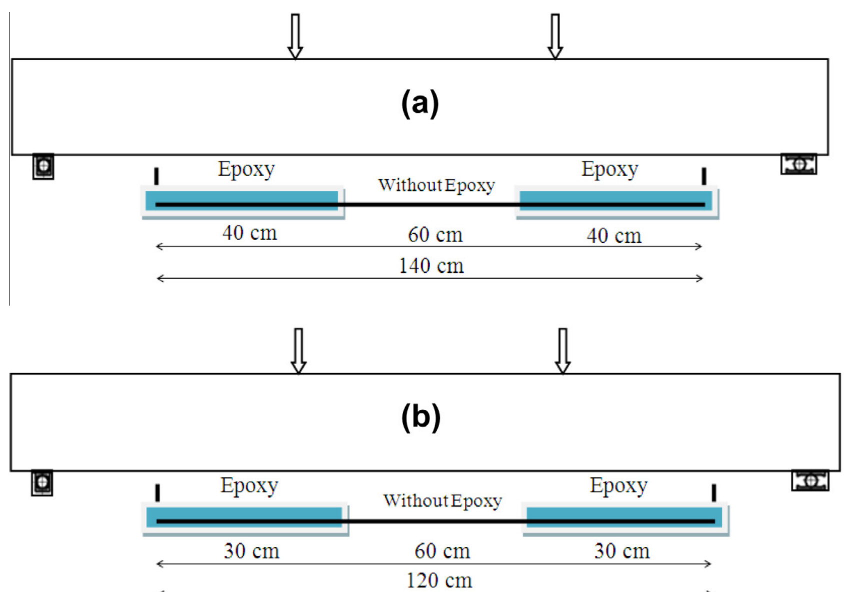

Fig. 2. Partially length epoxy details; (a) 1400 mm GFRP length and (b) 1200 mm GFRP length.

Several researchers [1,29–32] used novel self-anchored fiber-reinforced polymer bars to delay the onset of debonding and to ensure that the NSM FRP reinforcement continues to contribute to member strength after partial debonding. Some of these techniques needed to drill deep holes in the beams to insert the spikes [29], or side planted bolts [30] or steel connectors [1]. Although steel rebar has ribs that bind it mechanically to concrete, it can still pulled out from concrete under high stresses, an occurrence that often accompanies a larger-scale collapse of the structure. To prevent such a failure, steel rebar is either deeply embedded into adjacent structural members (40–60 times the diameter), or bent and hooked at the ends to lock it around the concrete and other rebar. Based on this old idea, the authors in the present work used FRP bars with 90°/45° degree bent ends as a novel self-anchored fiber-reinforced polymer bars.

Sharaky et al. [1,33–35] studied the bond and flexural behavior of NSM strengthened elements with different material types, epoxy properties, bar size and number of NSM bars using two different techniques to delay or prevent the concrete cover separation or end slip. In the first technique mechanical end anchor was used. In this technique, vertical holes of 10 mm in diameter and 200 mm in depth were drilled to install steel bars inside them using epoxy. The steel bars were connected to steel tubes using screws and the steel tubes were bonded to the ends of the NSM bars [1]. In the second technique transverse wrapping were bonded to the tension side of the concrete beams. The two techniques increased beam stiffness, yield load and the ultimate load of the strengthened RC beams. On the other hand, beam deflection decreased and concrete cover separation delayed. The use of transverse wrapping delayed the concrete cover separation and increased the ultimate load of the strengthened RC beams by 121.6% compared to the unstrengthened beam.

In the present work, the authors suggested a new method to prevent concrete cover separation and FRP bars debonding by using NSM GFRP bars with bent ends as self-anchored. The new self-anchored NSM GFRP bars were fabricated with bent ends