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FRP-strengthened RC slabs anchored with FRP anchors

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ABSTRACT

An abundance of tests over the last two decades has shown the bending capacity of flexural members such as reinforced concrete (RC) beams and slabs to be enhanced by the bonding of fibre-reinforced polymer (FRP) composites to their tension face. The propensity of the FRP to debond, however, limits its effectiveness. Different types of anchorages have therefore been investigated in order to delay or even prevent debonding. The so-called FRP anchor, which is made from rolled fibre sheets or bundles of lose fibres, is particularly suitable for anchoring FRP composites to a variety of structural element shapes. Studies that assess the effectiveness of FRP anchors in anchoring FRP strengthening in flexural members is, however, limited. This paper in turn reports a series of tests on one-way spanning simply supported RC slabs which have been strengthened in flexure with tension face bonded FRP composites and anchored with different arrangements of FRP anchors. The load–deflection responses of all slab tests are plotted, in addition to selected strain results. The behaviours of the specimens including the failure modes are also discussed. The greatest enhancement in load and deflection experienced by the six slabs strengthened with FRP plates and anchored with FRP anchors was 30% and 110%, respectively, over the unanchored FRP-strengthened control slab. The paper also discusses the strategic placement of FRP anchors for optimal strength and deflection enhancement in FRP-strengthened RC slabs.

1. Introduction

Numerous experimental investigations have proven the ability of fibre-reinforced polymer (FRP) composites to increase the flexural capacities of beams and slabs when bonded to their tension faces [1,2]. Numerous studies have also observed the FRP to debond at strains well below its rupture strain. Such premature failure, which has been observed to initiate at the base of flexural and flexural-shear cracks along the length of the member (e.g. IC debonding, [2]) or at the FRP plate end (e.g. concrete cover separation, [2]), can occur in a relatively sudden manner and constitutes an under-utilisation of the strength and strain capacity of the FRP. Mechanical anchorage of the FRP offers a real solution to the debonding problem and several different systems have been trialed to date. They include, but are not limited to, embedded metal threads [3], nailed plates (also known as hybrid bonding [4]), U-jackets [5], near-surface mounted rods [6], and anchors made with FRP [7] (also known as spike anchors but herein referred to as *FRP anchors* or *anchors*). FRP anchors are versatile as they are non-corrosive and can be applied to wide dimensioned elements such as slabs and walls. A recent review of FRP anchors is provided in [7] while a review of other anchorage methods (including FRP anchors) is presented in [8]. The anchorage of steel strengthening plates using metallic bolts is a related field of research (e.g. [9]), however, it is outside the scope of this paper and is therefore not considered further.

Fig. 1. is a schematic representation of the face of a concrete member which has been strengthened with an externally bonded FRP plate and anchored with an FRP anchor. Such an anchor is essentially made from glass or carbon fibres in which fibre sheets are folded or rolled, or lose fibres are bundled together. One end of the anchor (herein *anchor dowel*) is inserted into an epoxy filled hole in the concrete substrate (Fig. 1(b)) and the other end of the anchor is passed through the externally bonded FRP strengthening plate (herein *FRP plate* or *plate*). The free ends of the fibres (herein *anchor fan*) are splayed and epoxied onto the surface of the plate in order to disperse local stress concentrations. The double anchor fan arrangement (herein *bow-tie*) shown in Fig. 1 has been tailor made for the test slabs reported herein. As a precursor to the bow-tie anchor fan form, Smith [10] reported FRP anchors with a single fan component to increase the shear strength and slip capacity of FRP-to-concrete joints by up to approximately 70% and 800%, respectively, over unanchored control joints. The relative difference between the strength and the behaviour of single fan and bow-tie anchors in FRP-to-concrete joint tests has also been summarised in [10]. While Smith [10] reported both types of

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