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FRP Anchors to Enhance Efficiency of Externally Bonded FRP – Design Methodology and Case Studies

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Abstract

As the use of externally bonded fibre-reinforced polymer (FRP) reinforcement (EBR) systems for the retrofit of existing concrete structures becomes more prevalent, engineers and researchers are focusing on the use of FRP spike and through-anchors to enhance the efficiency of EBR systems. In addition to mitigating or delaying undesirable EBR debonding failure with spike anchors, through-anchors are also used to provide load-path continuity of the EBR across structural members. This paper briefly discusses the uses of FRP anchors for a wide-range of applications, as well as a recently developed design methodology for FRP anchors. The paper also describes how FRP anchors have been utilized in several field applications and the design of the anchors following the aforementioned methodology. The paper concludes that the use of FRP anchors is maturing, and that engineers now have the tools for the design of FRP anchors. Additionally, with recent developments in the understanding of anchor failure modes and the development of a resulting design methodology, there is a growing body of knowledge and experience for the adoption of anchor design into codes and guidelines.

Keywords: FRP, EBR, Spike, Anchor, Design

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Introduction

Engineers around the world have adopted externally bonded FRP for conventional strengthening, such as the enhancement of shear and flexural capacity, to existing concrete members like beams, slabs and columns. With such widespread use, engineers are also becoming cognisant that for most applications the enhancement in strength provided by FRP is controlled by debonding of the FRP from the concrete substrate and that, very often, only a fraction of the full potential of the FRP is utilized. Additionally, the use of FRP for seismic and blast retrofit is also gaining acceptance. In such applications the actual demands on the structural members cannot be precisely determined and the designs must be based on capacity principles. This means that either a lot of conservatism must be incorporated in the design or that the debonding failure of FRP must be reliably mitigated. As a response to these real design limitations, engineers are turning to the use of FRP spike and through anchors to mitigate this undesirable failure mode from controlling designs. However, current FRP design guidelines and codes do not include design provisions for FRP anchors [1,2]. As a result, researchers are also focusing on defining the benefits of anchors and developing design tools for such anchors [3,4,5]. Typical FRP spike and through anchors are shown in Figure 1.

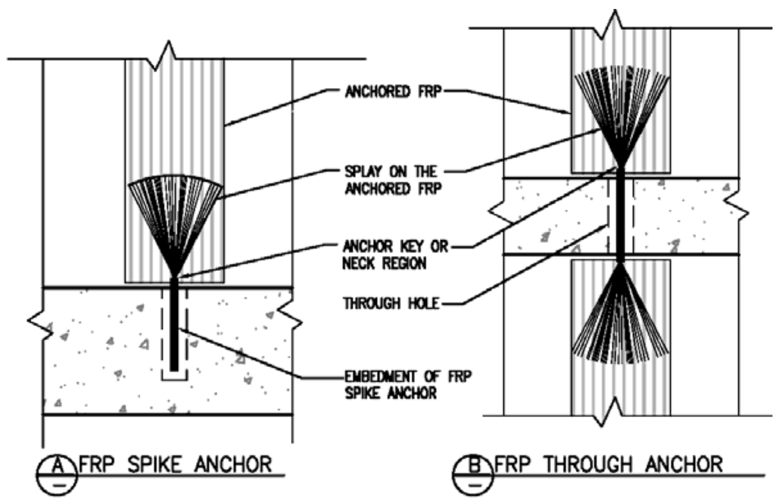

Figure 1: Typical FRP spike and through anchors

Currently, the design of FRP anchors and the resulting anchored FRP is mostly based on empirical data either from different researchers or on guidance provided by FRP manufacturers. Very often, such empirical data must be extrapolated to the specific application being considered by the engineer and may not address all the possible failure modes. The authors recently published the first comprehensive design methodology for FRP anchors [6]. This methodology is based on semi-empirical models available in the literature and addresses all the observed failure modes for FRP anchors, such as concrete pull-out for embedded spike anchors, tensile rupture of the anchors at the key (or neck) section and debonding of the anchor splay from the anchored FRP. This methodology has been used by one of the authors in several recent field applications and described subsequently.

Field Applications of FRP Anchors

For strengthening of structures to resist gravity loads, the most common use of FRP anchors has been the anchorage of the FRP used to strengthen beams in either shear or flexure. For seismic strengthening of existing structures anchors have been used to terminate, develop or continue FRP at columns, shear walls and diaphragms. This article focuses on the use of anchors for seismic strengthening.

Concrete Columns and Walls

One of the early applications of FRP anchors was in the 2009 seismic retrofit of the piers at the SR99 Aurora Avenue Bridge in Seattle, Washington, USA. The cruciform shaped columns had to be shear strengthened with FRP as shown in Figure 2. The first author was one of the consultants during the scaled model tests at Washington State University to confirm that FRP anchors at the re-entrant corners would prevent debonding of the FRP and allow the development of the required shear strength in the FRP.

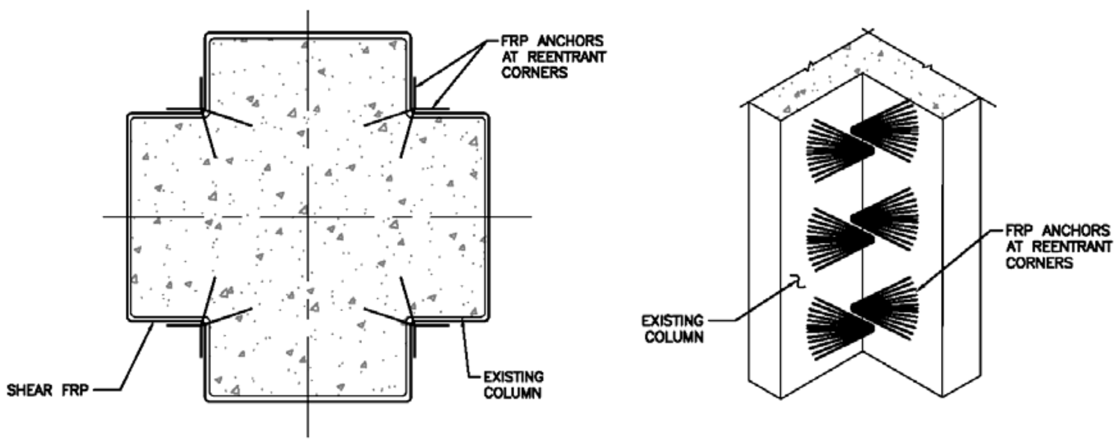

Figure 2: FRP spike anchors at column re-entrant corners

Another common application is the confinement of existing columns across walls framing into the column (Figure 3). Concrete shear walls are routinely strengthened for both flexure and shear. Flexural (vertical) FRP at the wall ends can be either developed at the foundation or continued across floor slabs as shown in Figure 1. Shear (horizontal) FRP on the walls can be anchored with spike anchors as shown in the plan in Figure 3.

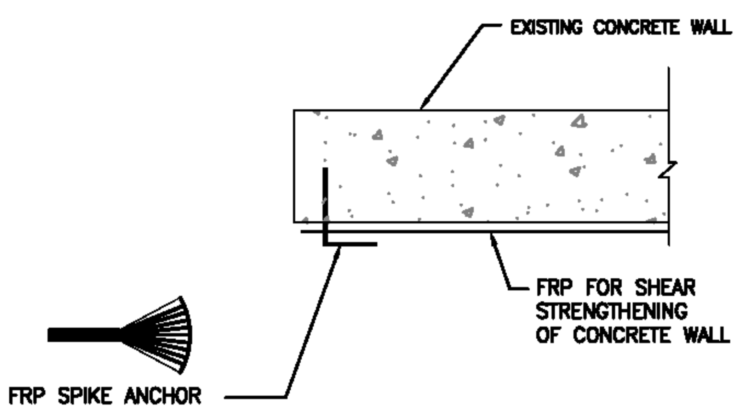

Figure 3: Plan view showing FRP spike anchors at wall FRP termination

Wall end boundary elements are confined for high compressive forces similar to the column in Figure 4. Through anchors are often used to continue the FRP across the wall.

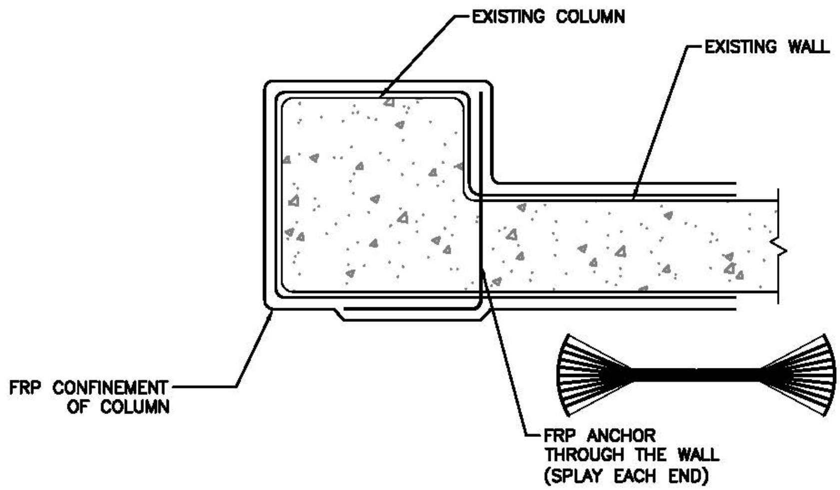

Figure 4: FRP through anchor to continue column confinement FRP across wall

Diaphragms

Diaphragms are also increasingly being strengthened with FRP. Such strengthening can include shear strengthening of the diaphragms as well as strengthening of chord members and collectors, which “collect” inertial load and deliver it to the lateral force resisting elements. Figure 5 shows how FRP anchors are incorporated to anchor FRP for slab shear strengthening and within a slab-to-wall shear force transfer detail.

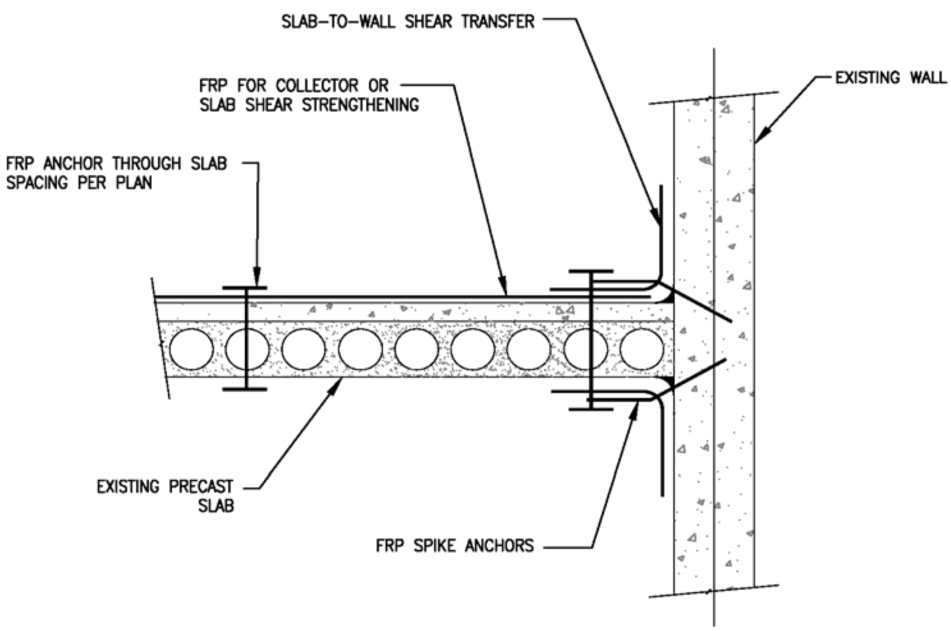

Figure 5: Section at slab-wall intersection showing FRP spike and through anchors

Anchor Design Methodology

FRP anchors exhibit a variety of failure modes which must be taken into consideration for design. The failure modes can be grouped into the following broad categories: failure within the concrete at the embedded end of spike anchors; rupture of the anchors, predominantly at the anchor neck/key; and debonding of the splay from the anchored FRP (Figure 6).

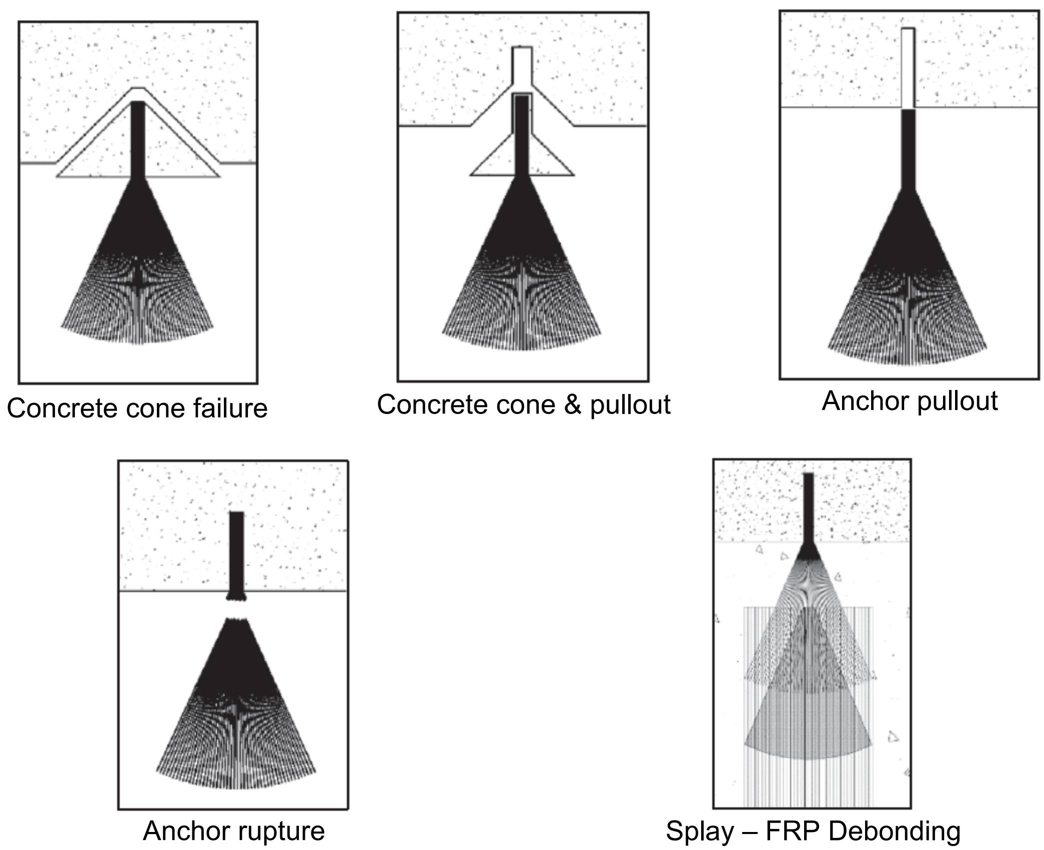

Figure 6: Potential FRP anchor failure modes

The authors independently developed characteristic value design equations for each of these failure modes [3,4,5]. These semi-empirical design equations were then combined into a comprehensive design methodology [6]. The advantage of this design methodology is that it allows the design of FRP anchors for a wide range of applications by utilizing the force to be developed by the anchor as the main design parameter. This force can easily be obtained by determining the required effective strain in the anchored FRP and multiplying this strain by the elastic modulus of the FRP. This flexibility permits the design methodology to be used with any of the available design code or guidelines. The design methodology yields the amount of fibres in the anchor, the drilled hole diameter and embedment depth and the configuration of the splay, i.e. a complete representation of the required anchor. For ultimate capacity level design, the anchors can be sized to rupture the FRP being anchored while for gravity load resistance the anchors can be designed to develop the required strain in the FRP.

Summary

As described in this paper, FRP anchors have been used in seismic retrofit for more than a decade but their utilization is growing rapidly. The examples shown in the paper illustrate that FRP anchors are being used in a very wide variety of applications and configurations. Until recently, design of such anchors involved detailed literature surveys and extrapolation of the information in the available literature. With the recent development of semi-empirical models, designers can now consider all the potential failure modes. The comprehensive methodology published recently by the authors [6] offers designers a direct and step-by-step approach for anchor designs based on actual the actual FRP force or strain demand levels. Design guidelines such as ACI 440.2R [1] have also taken note of the paucity of anchor design information and are currently in the process of developing prescriptive provisions for the use of FRP anchors. The proposed design methodology is being utilized to support this effort. In future, it is expected that design guidelines will incorporate a complete methodology to permit the design of FRP anchors for a wide variety of applications.

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