Seventh Asia-Pacific Conference on FRP in Structures (APFIS 2019)
Surfers Paradise, Gold Coast, Australia, 10-13 December 2019
S.T. Smith, T. Yu, D. Fernando and Z.Y. Wang (Eds.)

QUALITY CONTROL AND ASSURANCE FOR FRP ANCHORS – CURRENT PRACTICE AND PATH FORWARD

R. Kanitkar[1]*, E. del Rey Castillo[2], S.T. Smith[3] and H. Rasheed[4]
[1] KL Structures, Texas, USA
[2] Department of Civil and Environmental Engineering, University of Auckland, New Zealand
[3] Faculty of Engineering Computer & Math Sciences, University of Adelaide, South Australia
[4] Department of Civil Engineering, Kansas State University, Manhattan, Kansas, USA
Email: ravi@klstructures.com, e.delrey@auckland.ac.nz, scott.smith@adelaide.edu.au, hayder@ksu.edu
* Corresponding Author

ABSTRACT
Anchorage of externally bonded fiber-reinforced polymers (FRP) is now widely accepted as a means of mobilizing higher strains in FRP plates externally bonded to concrete surfaces for strengthening purposes, by delaying or mitigating debonding. For seismic applications, anchorage of the FRP can serve to provide additional capacity and load path redundancy for larger than expected seismic loads. A commonly used means of anchoring FRP is the use of fiber (spike) anchors, whose effectiveness has been confirmed by experimental research. Very little attention has, however, been paid to the quality control and assurance of such installed anchorage devices. This paper presents a commentary on issues associated with anchor installation as well as related quality assurance (QA) and quality control (QC) aspects. The paper also discusses potential effects on the performance of the entire FRP strengthening system, as well as suggesting measures to improve the reliability of such anchors.

KEYWORDS
FRP, anchors, spike, quality control, quality assurance, field testing.

INTRODUCTION
Anchors made from fiber-reinforced polymer (FRP) composites (herein referred to as *spike anchors* or *FRP anchors*) have become a popular means to anchor externally bonded FRP strengthening systems onto concrete substrates (del Rey Castillo et al. 2019a). The anchors can enable higher strains in the FRP and allow the strengthened member to exhibit greater deformability. A typical FRP anchor is shown in Figure 1. The anchor is comprised of two main components, namely a dowel component which is installed into a hole drilled in the substrate, and a splay or fan component which is spread out over, and adhered to, the externally bonded FRP. Such anchors are used for a wide variety of applications, ranging from anchoring U-wraps for beam shear strengthening to transferring force from FRP to a foundation. The effectiveness of FRP anchors has been confirmed experimentally by several researchers to date and the state-of-the-art has been described in recent papers (Kalfat et al 2018, del Rey Castillo et al 2019d).

Currently available international FRP design guidelines and standards (e.g. ACI 440 2017) mention the benefits of anchoring FRP in qualitative terms without any guidelines for design. Although such documents discuss quality control and assurance for the externally bonded FRP, they are silent on such issues for the fabrication and installation of FRP anchors. The authors have extensive experience in research as well as in practical applications of FRP anchors in FRP-strengthened RC. Based on this experience, this paper attempts to highlight the issues related to quality control and assurance for FRP anchors.

FIELD EXPERIENCES AND OBSERVATIONS

As shown in Figure 1, FRP anchors are typically fabricated as bundles of loose raw fibers or as long ropes of fiber which can be cut to size. These raw fiber bundle anchors (RFB) are saturated with epoxy by being soaked in an epoxy bath and then manually manipulating the fibers to ensure full epoxy impregnation. Then, the excess epoxy is removed by hand or by passing the fibers through a die. This manual manipulation can result in damage to and misalignment of the saturated fibers. The anchors are then installed into drilled holes pre-filled with epoxy or paste with the help of a tool, such as a wire or screwdriver.

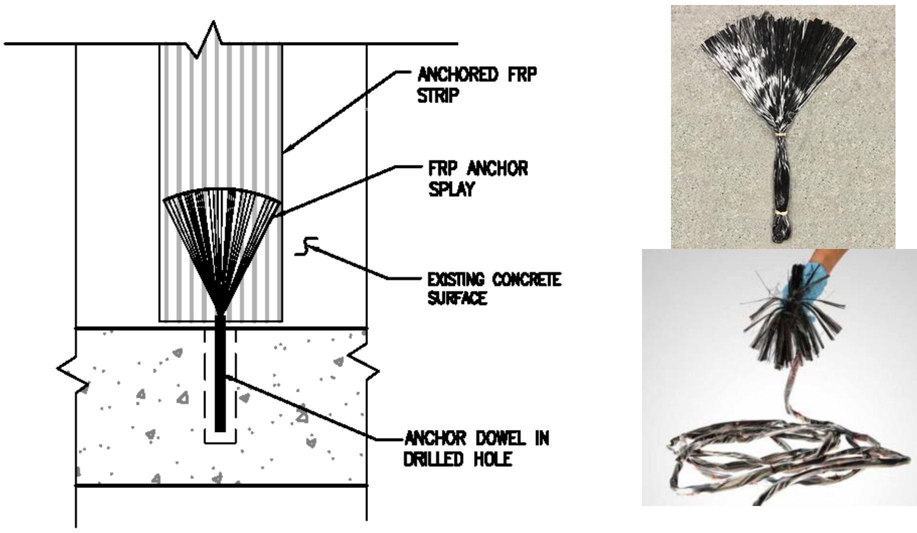


Figure 1. Typical fiber anchor as supplied and installed

Installation of RFB anchors in the field is often a slow and time-consuming task. When a large number of anchors are to be installed, the tool used to insert the anchors becomes sticky with epoxy and as a result the fibers tend to pull out of the hole when the tool is withdrawn, making it very difficult to achieve the desired embedment depth. In some cases, air can be trapped at the bottom of the hole or between the fibers. Anchor installation can thus become solely dependent on the contractor experience, i.e. an art rather than a precise skill.

Based on field observations, the authors conclude that the most significant impact of the currently prevalent anchor installation techniques is the variability of the final installation. The potential damage and misalignment of the fibers can adversely impact quality control; namely variable saturation, unknown depth and condition of the anchor in the hole can affect quality assurance. Inspection is severely handicapped as it is impossible to verify any of the above quality control and assurance issues. The resulting installation could mean that every anchor in the project has been installed differently resulting in unreliability that could affect design and performance of the strengthening system. This is deemed to be unacceptable to either the designer, the installer or the client. This situation is further exacerbated by the fact that no known field test method has been developed for FRP anchors. In a recent simulation, an experienced FRP installer was asked to install RFB anchors into holes drilled in 5cm x5cm x 20cm long concrete blocks. The intent was to create as-installed samples of anchor installation that could then be studied for potential variability. Figure 2 shows two of samples after they were cut down the middle. It can be seen that, within the hole, there are instances of unsaturated fiber, misaligned fiber, air gaps within the body of the anchor as well as at the bottom of the hole. This variability could be far greater for field-installed anchors where conditions are not as controlled as in a workshop. The variability, and resulting unreliability, of the installation could be a real concern, especially in the field where hundreds (and in cases thousands) of anchors are to be installed.

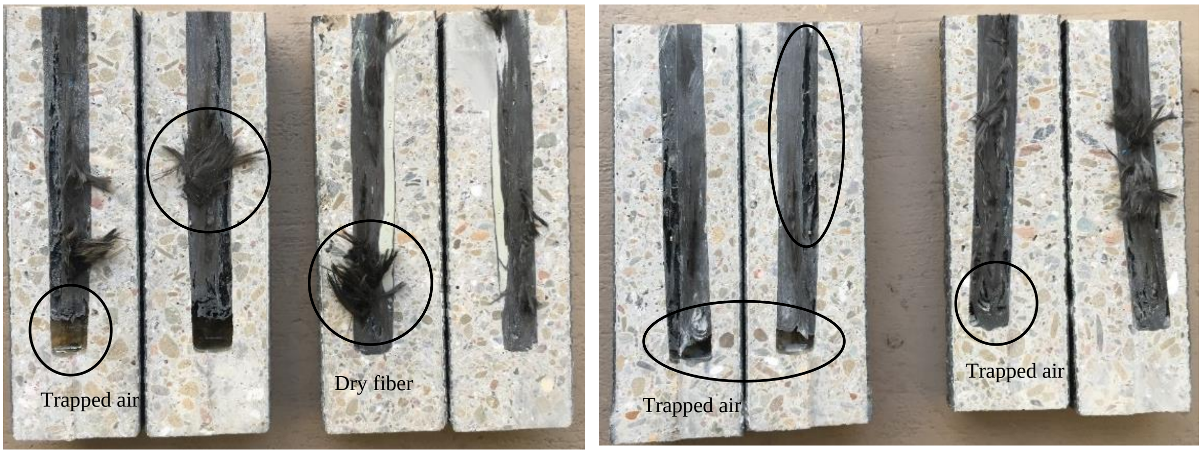
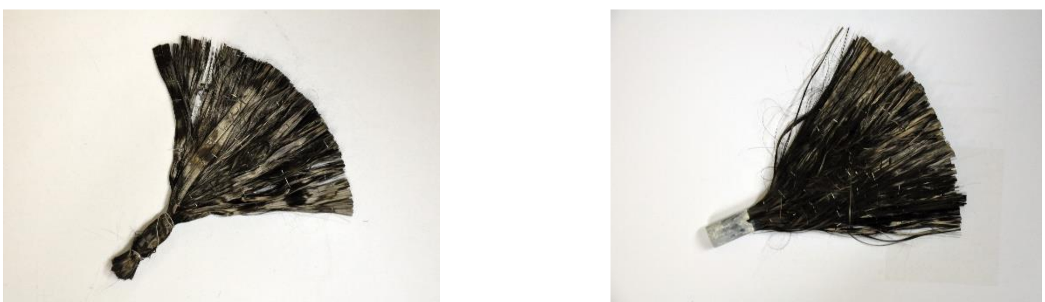


Figure 2. Cut concrete samples showing RFB anchor conditions within drilled hole

LABORATORY EXPERIENCES AND OBSERVATIONS

The authors have investigated and have utilized a variety of FRP anchors and installation procedures. Although anchor installation in the laboratory tend to be far more uniform than in the field, the following examples illustrate the variety in anchor installation techniques and the resulting impact on quality and performance.

Zhang et al. (2010) investigated the manufacture and installation of two different types of FRP anchors, referred to as dry (RFB) and dowel (with a impregnated and precured end) FRP anchors in Figure 2 onto FRP-concrete single lap shear joints. The dry anchors were made from bundles of fibers that were directly inserted into epoxy filled holes, without fiber impregnation. The dowel anchors, which consisted of a precured portion made from fibers saturated with epoxy, were inserted into epoxy filled holes. Both types of anchors were made by hand in a process that was meant to mimic field conditions and practices. While both anchor types are applicable and relevant to field applications, the dowel anchors were considered superior as they yielded the greatest joint strengths and FRP-concrete slip capacity.



(a) Dry FRP anchor (b) Impregnated FRP anchor

Figure 2. FRP anchors types (Zhang et al. 2010)

Zaki and Rasheed (2019) studied the efficiency and practicality of the installation technique on the performance of full-scale beams strengthened with CFRP sheets anchored with FRP anchors. They compared installing the FRP anchors prior to applying the sheets against the installation of the anchors after the application of the sheets. The second technique was found to be superior to the first one since the installation time was cut in half. In addition, only half the number of installation personnel was needed, while the fiber alignment was much better and the performance was improved for identical fiber anchor content. Furthermore, Zaki et al. (2019) examined two types of spike anchors side by side, namely, RFB anchors and precured dowel anchors, where the anchor embedded portion is precured into a dowel. The testing showed that precured dowel anchors yielded much stiffer response while all RFB anchors exhibited more ductile response causing them to fail first due to reaching a shear strain limit. This difference is potentially due to the incomplete soaking of fibers in RFB anchors, as previously reported in the literature (Zhang et al. 2010).

Del Rey Castillo et al used RFB straight and bent anchors for a large experimental campaign on small component testing (del Rey Castillo et al. 2019b, c). Ensuring full soaking of the fibers on RFB anchors is labor intensive and it is a delicate process that requires large amounts of resin and results in extremely low fiber volume ratio (as low as 0.2). Low fiber volume ratios are not desired because large anchors are not as effective as small anchors, so reducing the size of the cured anchor (for a constant fiber volume) will result in more effective applications. Furthermore, low fiber volume ratios result in larger holes to drill, thus increasing the likelihood of drilling through reinforcing steel and weakening the existing structural element. Recent unpublished testing by del Rey Castillo with dowel anchors highlighted the difficulty to properly soak fibers in the precured dowel-dry fibers interface, and the more brittle failure when the saturation was inadequate. Finally, proper filling of the pre-drilled hole with resin needs to be ensured, or the anchors are susceptible to premature pull-out failure.

PATH-FORWARD

It can be seen that there are critical quality control and assurance issues associated with the saturation and installation of FRP anchors. For the externally bonded FRP, the use of field adhesion tests and the creation/testing of tensile coupons serve as installation and material QA/QC criteria. Currently, the only criteria for FRP anchors involve weighing the dry and saturated anchors. However, this does not provide any insights into whether the fibers are fully saturated. There are no available criteria for the installation of FRP anchors. One solution may be the creation of concrete blocks within which anchors are installed on site, to the project specifications, using the proposed installation approach. These blocks could then be jacked apart with an open loop jack in the field to quantify the ultimate shear load carrying capacity of a single anchor regardless of installation errors. The work will be accepted based on jacking apart two blocks up to anchor failure in three different attempts and selecting the lowest anchor shear capacity to meet the design criterion. Another approach could be the use of field-testing of anchors, similar to that commonly performed for adhesive metallic fasteners. Using such a test, certain number of anchors of each type could proof-tested on site. In addition to the above, it is important that manufacturers develop detailed and clear installation manuals and checklists, along with training of the installers.

CONCLUSIONS

Fiber anchors are a critical tool in the FRP strengthening tool kit, but current fabrication and installation methods for FRP anchors can lead to significant variability in the installed anchors, along with potential unreliability of performance of the strengthened member. This should not be acceptable for the different stakeholders. Although quality control issues are seen with both RFB and dowel anchors, it appears that dowel anchors show great promise in having less variability in fabrication and installation. It is well understood that the performance of fiber anchors for concrete related failure modes is similar to that of metallic anchors post-installed in concrete with adhesive (Kim and Smith 2010). Improvements in installation of metallic anchors offers a good opportunity to enhance the current techniques for fiber anchors. Development of field testing would also provide a good tool for qualification of fiber anchors. Finally, additional testing could be done to understand the effect of anchor installation variability on the performance of strengthened concrete members.

REFERENCES

ACI 440 (2017) *Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures*, American Concrete Institute (ACI), Committee 440, USA.

Kalfat, R., Gadd, J., Al-Mahaidi, R. and Smith, S.T. (2018) “An efficiency framework for anchorage devices used to enhance the performance of FRP strengthened RC members”, *Construction and Building Materials*, Vol. 191, pp. 354-375.

Kim, S.J. and Smith, S.T. (2010) "Pullout strength models for FRP anchors in uncracked concrete", *Journal of Composites for Construction*, Vol. 14, No. 4, pp. 406–414.

del Rey Castillo, E., Kanitkar, R., Smith, S.T., Griffith, M.C. and Ingham, J.M. (2019a.) "Design approach for FRP spike anchors in FRP-strengthened RC structures", *Composite Structures*, Vol. 214, pp. 23–33.

del Rey Castillo, E., Griffith, M., and Ingham, J. (2019b) "Straight FRP anchors exhibiting fiber rupture failure mode", *Composite Structures*, Vol. 207, pp. 612-624.

del Rey Castillo, E., Dizhur, D., Griffith, M. and Ingham, J. (2019c) "Experimental testing and design model for bent FRP anchors exhibiting fiber rupture failure mode", *Composite Structures*, Vol. 210, pp. 618-627.

del Rey Castillo, E., Dizhur, D., Griffith, M. and Ingham, J. (2019d) "Strengthening RC structures using FRP spike anchors in combination with EBR systems." *Composite Structures*, Vol. 209, pp. 668-685.

Zaki, M.A. and Rasheed, H.A. (2019) "Impact of efficiency and practicality of CFRP anchor installation techniques on the performance of RC beams strengthened with CFRP sheets", *Canadian Journal of Civil Engineering*, *46(9)*, *796-809*.

Zaki, M.A., Rasheed, H.A. and Alkhrdaji, T. (2019) "Performance of CFRP-strengthened concrete beams fastened with distributed CFRP dowel and fiber anchors", *Composites Part B: Engineering*, Vol. 176, pp. 107117.

Zhang, H.W., Smith, S.T. and Kim, S.J. (2012) “Optimisation of carbon and glass FRP anchor design”, *Construction and Building Materials*, Vol. 32, pp. 1-12.