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CASE STUDIES OF USING FRP ANCHORS IN NEW ZEALAND

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ABSTRACT

The New Zealand Building Act of 2004 established the framework for seismic assessment and strengthening of existing buildings, and the Canterbury Earthquake sequence has highlighted the importance of such efforts. FRP materials are sometimes preferred over other options for strengthening of existing buildings, mainly for the light weight, versatility and durability of the material. As a result, the use of FRP materials as Externally Bonded Reinforcements (EBR) for the strengthening of existing structures has increased significantly in New Zealand over the last years.

A few case studies have been compiled and are briefly summarised herein, focusing on the function that the FRP anchors fulfill. Detailed descriptions, the calculations and analyses cannot be included due to space limitations. The vast majority of the strengthening interventions in New Zealand are intended to improve the seismic behaviour of existing structures, and seismic strengthening is therefore the focus of this study. The use of FRP anchors to prevent or delay premature debonding, to ensure the continuity of the load path from the FRP materials into the structure and provide redundancy to the seismic load path has become widespread in seismic strengthening schemes. The paper focuses on the various ways in which FRP anchors are used in seismic strengthening.

KEYWORDS

FRP, FRP anchors, application, seismic, strengthening

INTRODUCTION

New Zealand is a highly seismic country, which entails a significant risk for the existing built stock. The Building Act of 2004 established a system, which was updated in 2017, for identifying earthquake prone buildings to support the legislation and encourage more consistency when undertaking assessments of existing buildings. With the help of the technical tools developed in conjunction with the New Zealand Building Act, buildings receive a rating based on the percentage of a New Building Standard, or %NBS. The minimum legal requirement for existing buildings is 33%NBS, with more stringent requirements for critical buildings such as hospitals or police stations. Additionally, tenants, lenders or insurers often require higher %NBS levels, especially in more hazardous areas such as Wellington. The Building Act also established a timeline of when owners and Councils need to assess and strengthen their buildings, depending on the earthquake hazard of that determined area.

New Zealand has not developed any specific guidance for seismic strengthening methods, and engineers typically resort to international standards and codes, such as ACI 440.2R (2017) or CNR-DT 200 (2013), when designing a strengthening scheme using Externally Bonded Fibre Reinforced Polymer systems (EBR-FRP). Among the numerous methods to enhance the seismic capacity of existing structures, the use of EBR-FRP systems is often preferred, mainly because of the light weight of the material, the versatility of the application and the unobtrusiveness (Kalfat et al. 2011). These benefits allow engineers to implement a wide variety of design strengthening interventions that can fit almost every situation while avoiding adding to the seismic weight and maximizing the use of floor space.

FRP ANCHORS

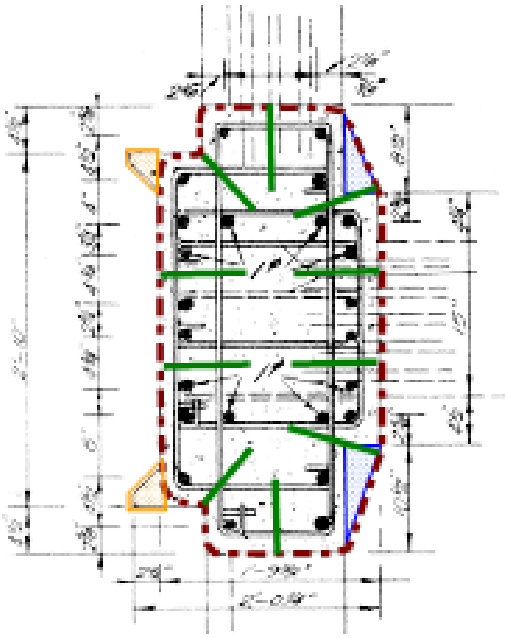
The main deficiency of EBR-FRP systems is the premature debonding of the FRP from the concrete substrate due to the low tensile strength of the concrete in comparison to the tensile strength of the FRP material (Lau et al. 2001). One way to overcome this problem is the use of FRP anchors, which consist of bundles of fibres soaked into epoxy. During installation, one end of the anchor is introduced into the structure, while the other end is splayed out and bonded to the surface of the EBR-FRP sheet (Kalfat et al. 2018; del Rey Castillo et al. 2019). FRP anchors also ensure the continuity of the load path between the FRP system and the structural element, prevent or delay the debonding of the FRP from the substrate and provide an added layer of redundancy if a larger-than-expected earthquake occurs.

For years, the main barrier to wide implementation of FRP anchors was the lack of a design methodology. In recent investigations, the various failure modes for FRP anchors were taken into consideration to develop design equations, with the concrete-related failure modes being firstly investigated (Kim & Smith 2010), followed by the fan-to-sheet failure (Kanitkar et al. 2016) and finally fibre rupture failure (del Rey Castillo et al. 2019b; del Rey Castillo, et al. 2019a). The resulting design equations obtained from those studies were combined by the authors in a global design methodology that is now available for engineers to use (del Rey Castillo et al. 2019). FRP anchors were initially manufactured using rolled unidirectional sheets, but their use has long been discontinued, in favour of either completely dry or partially pre-cured anchors, as illustrated in Figure 1

Figure 1. Examples of a dry anchor at the top and a partially precured anchor at the bottom

FRP ANCHOR APPLICATIONS IN NEW ZEALAND

The most common application of FRP materials in New Zealand is to improve the seismic capacity of existing structures. One of the earliest uses of FRP for seismic strengthening of structures was the confinement of columns to improve the ductility by preventing bar buckling and axial/compression failure (Seible et al. 1997). Columns can often have reentrant corners, and FRP anchors installed, as illustrated in Figure 2a in green, are necessary to prevent the confinement jacket from pulling away. FRP anchors are also used if an obstruction prevents the confinement to be fully wrapped around the columns, as shown in Figure 2b where the anchors thread across the wall to fully extend around the column. Flexural strengthening of columns is sometimes included in addition to confinement, but this application is not as common (del Rey Castillo et al. 2018). Another common use of FRP anchors is to wrap coupling beams, which are frequently used in combination with shear concrete walls to resist lateral loading from the earthquake. Insufficient confinement of the longitudinal bars may cause the failure of these beams at lower ductility levels, and FRP anchors complete the confinement around the beam as shown in Figure 2c. One final example of the use of FRP anchors in New Zealand is to strengthen floor diaphragms, typically in combination with a grid of orthogonal FRP sheets bonded to the floor diaphragm. The FRP anchors are used to transfer the forces from the FRP sheets to the bond beam or perimeter walls and complete the diaphragm action, as shown in Figure 2d.



) Example of using FRP anchors (in green) to prevent popping out of the confinement layer (in red dash)

(b) Example of using FRP anchors to close the confinement and bypass obstructions

(c) Example of using FRP anchors to close the confinement of a coupling beam

(d) Example of using FRP anchors to transfer the forces to the perimeter

Figure 2. Examples of using FRP anchors in New Zealand

CONCLUSION

FRP anchors are a versatile anchorage solution for EBR systems, and can be used for a wide range of applications. The most common applications in New Zealand are seismic-related, such as confinement of columns, coupling beams or floor diaphragms. FRP anchors are typically required in seismic applications to create redundancy in case a larger-than-expected earthquake occurs, which results in an extensive use of FRP anchors in New Zealand. Example of several applications were briefly summarized herein, but more detailed design information could not be included given the space constraints. Reference to published design examples for FRP anchors is provided instead.

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