COMMONLY ENCOUNTERED ISSUES IN DESIGN AND INSTALLATION OF CFRP SYSTEMS

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As the use of externally bonded carbon fiber reinforcing polymers (CFRP) becomes more common in the repair and restoration industry, practicing engineers and contractors are facing new challenges in utilization of these systems. Although the use of CFRP systems started as an alternate for surface mounted steel plates in corrosive environments, CFRP systems quickly became extremely popular due to their superior structural properties and durability. This article will review some of the commonly encountered issues in design and installation of externally bonded CFRP systems.

Externally bonded CFRP systems are great tools to increase the in-plane bending, out-of-plane bending, shear and compressive strength of existing concrete and masonry structural members. Although the CFRP systems are not very effective in increasing the sectional properties of the retrofitted members to help with deflection control, utilization of their superior tensile strength and confinement ability allows the engineers to increase the strength of existing members to meet strength requirements. In comparison to structural steel and concrete, FRP systems have the advantage of being lighter and easier (less intrusive) to install. As CFRP design is not commonly taught in universities, the structural design and detailing of CFRP systems require specific knowledge and training in the matter. While the basic procedures for designing CFRP for concrete and masonry structures are covered by ACI Committee 440's guidelines, the proper design and specification of CFRP materials require knowledge beyond the basic information provided by the ACI Committee 440's guidelines. Engineers specifying these systems need to have the knowledge in carbon fiber reinforcing polymers in general and their limitations (fire resistance, stain limits, tensile capacity…etc.). CFRP systems produced by different manufacturers may consist of very different components with varying structural properties; thus, the specifiers need to be diligent about the composition of the CFRP systems prior to choosing a reinforcing material. Furthermore, the materials used for anchorage to existing substrates and fire resistance vary significantly between manufacturers which should also be carefully be evaluated to ensure that the project conditions allow the use of desired CFRP systems prior to specifying them.

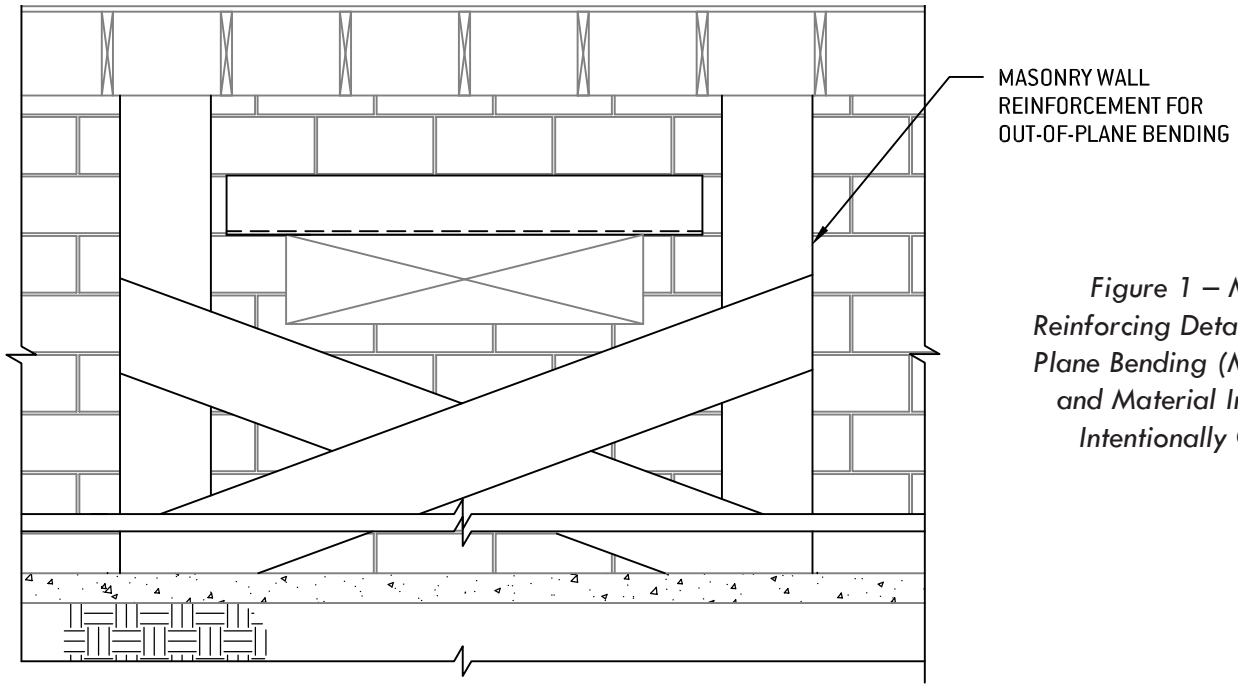

Figure 1 – Masonry Reinforcing Detail for Out of Plane Bending (Manufacturer and Material Information Intentionally Omitted)

Though a great deal of design information and case studies are available to practicing engineers involved in structural rehabilitation, it is rarely the case that the engineers specifying the use of externally bonded CFRP systems would provide complete details for the construction of CFRP systems on their drawings. Often times inadequate information is provided on structural drawings to the specialty engineers for performing calculations and generation of CFRP shop drawings; consequently, specialty engineers are asked to design and detail structural strengthening with inadequate structural information and for unknown performance requirements. It must be noted that ACI 440 guidelines clearly explain what information needs be on structural drawings for CFRP systems and the engineers should provide this information on structural rehabilitation drawings accordingly. In absence of complete details to install CFRP systems, engineers need to provide all

of their design calculations along with the expected performance requirements to the specialty engineers to be able to perform the required analysis per ACI 440 guidelines and generate shop drawings for installation. A review of the basic formulas and requirements for design, as a minimum, would allow the specifiers to understand what information needs to be given to the specialty engineers to be able to perform calculations and detail the necessary CFRP strengthening details.

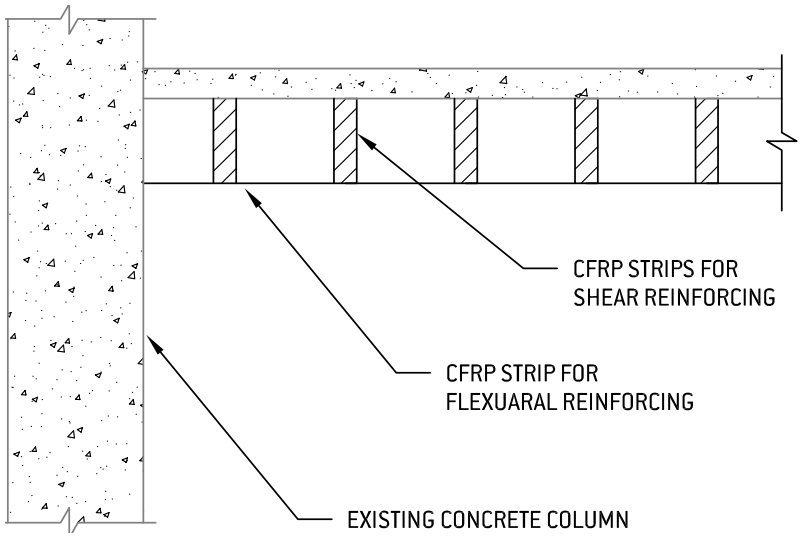

Figure 2 – Concrete Beam Reinforcing Detail for Shear and Bending (Manufacturer and Material Information Intentionally Omitted)

In addition to the above-mentioned issues in design, construction of externally bonded FRP systems require special precautions to be taken. Correct handling of the materials, surface preparation, following correct wet-layup and dry-layup procedures, and ensuring the use of correct number of layers crucial steps in installation. Personnel handling and installing the CFRP systems need to be trained by the material manufacturer specifically to ensure that the field personnel are competent in the installation of the materials. Obtaining the required bond strength in the field is another critical component in CFRP installation. Without sufficient bond capacity, CFRP assembly would simply de-bond from the substrate without making any contribution to the structural capacity of the member which is being retrofitted. Adhesion testing should be performed, prior to installation, to ensure that the required capacity, between concrete/masonry and CFRP systems, can be obtained in the field. The required bond strength and field testing procedures need to be clearly specified in the drawings to meet the requirements of the authorities having jurisdiction.

In addition to quality control procedures implemented by the contractors and installers, periodic inspections should be performed to verify the compliance of the installation with the project requirements. To comply with the Special Inspections requirements specified by the International Building Code, as well as the local jurisdictions, it is highly recommended that a realistic special inspections program is developed. Responsibilities of the special inspector and the frequency of the inspections for the CFRP systems need to be clearly conveyed to the contractors. Discussing the special inspections requirements with the local code enforcement officials, prior to specifying the inspections reequipments, is highly recommended to avoid issues during the permitting.

As CFRP systems are becoming more and more common in our industry, it is imperative for the specifiers to have a good understanding of the fundamentals behind the design and construction of these systems. Properly specifying the materials, performance requirements, testing and inspection procedures; providing adequate information to specialty engineers for generation of shop drawings are not just "good practices" but required items for constructability. Furthermore, the limitations and suitability of the CFRP systems for each project should be carefully prior to specification.

Citations:
"440.2R-17: Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures", American Concrete Institute Committee 440, 2017.
"440.7R-10 Guide for Design & Constr of Externally Bonded FRP Systems for Strengthening Unreinforced Masonry Structures", American Concrete Institute Committee 440, 2010.
"2012 International Building Code", International Code Council, 2012.

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