CHAPTER 7

DETAILING AND PRACTICAL EXECUTION IN CONCRETE

7.1 General

This chapter summarizes basic detailing and practical execution rules for the application of composites as externally bonded reinforcement.

7.2 Detailing

Detailing rules are summarized here for the three basic cases: (a) flexural strengthening, (b) shear strengthening and (c) confinement.

7.2.1 Flexural strengthening

According to the *fib* bulletin 14 (2001), the following rules should be respected (for beam strengthening):

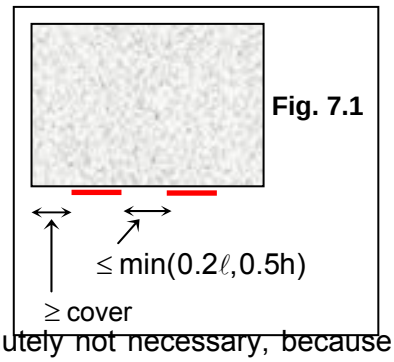


Fig. 7.1

- Maximum spacing between strips $= \min(0.2\ell, 5h)$, where ℓ = span length and h = total depth (in the case of cantilevers 0.2 should be replaced by 0.4).
- Minimum distance to the edge of the beam should equal the concrete cover of the internal longitudinal reinforcement.
- Lap joints of strips should be avoided; they are absolutely not necessary, because FRP can be delivered in the required length. Nevertheless, if needed, lap joints should be made in the direction of the fibers with an overlap that will ensure tensile fracture of the FRP prior to debonding at the lap joint.
- Crossing of strips is allowed (e.g. strengthening of two way slabs) with bonding in the crossing area.
- If strips or sheets are to be applied in several layers, the maximum number or layers should not exceed 3 or 5 for prefabricated strips or in-situ cured sheets, respectively.
- In the case of applying FRP strips over supports of continuous beams or slabs, the strips should be anchored at a distance in the order of 1 m in the compression zone (Fig. 7.2).

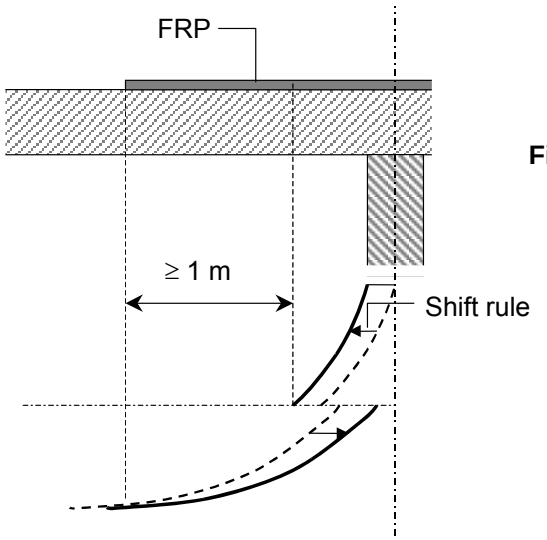


Fig. 7.2 FRP bonding above internal support.

- Anchoring of FRP (especially if the strips are staggered) can be ensured by applying bonded FRP “stirrups” that enclose the longitudinal strips at their ends (Fig. 7.3, 7.4). The use of such stirrups is strongly recommended. Note that these stirrups are not considered to be part of the shear reinforcement but are responsible to keep the longitudinal strips in their position and to prevent peeling-off.

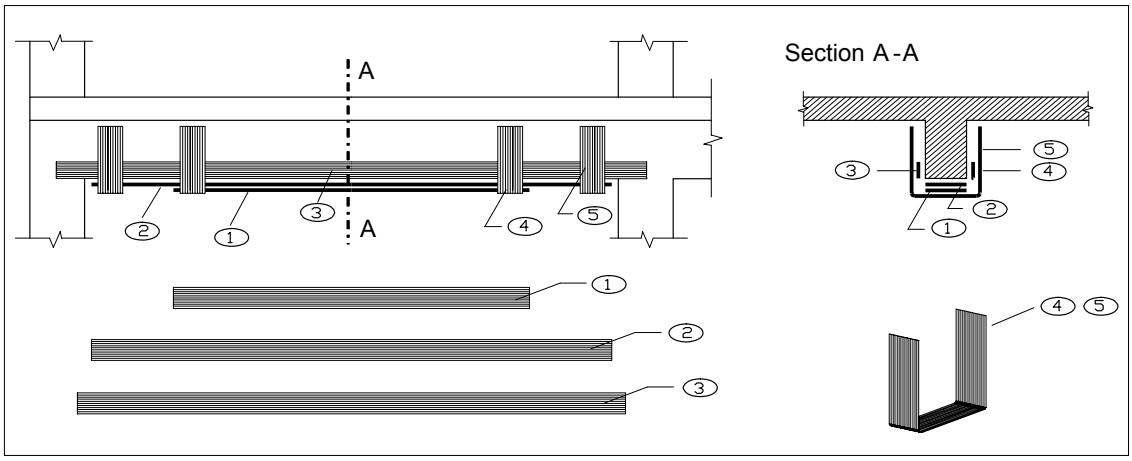


Fig. 7.3 Flexural strengthening with possible end anchorages.

Fig. 7.4 Improved anchorage at FRP strip ends using transverse FRP.

7.2.2 Shear strengthening

- In the case of strengthening T-beams, externally bonded FRP should be anchored in the compression zone (e.g. Fig. 7.5).

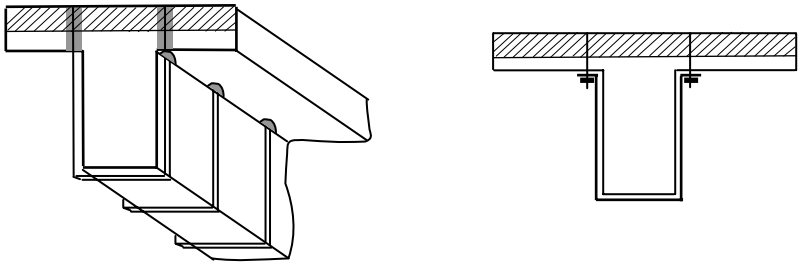


Fig. 7.5 Typical configurations for the anchorage of FRP "ties" in the compression zone.

- If anchorage in the compression zone is not possible, placement of sheets inside grooves at the top of the web is strongly recommended (Fig. 7.6). The rods inside the grooves could be non-metallic (e.g. FRP); if shear strengthening is provided with CFRP sheets and the rods are made of steel, the use of excessive resin inside the groove should ensure the non-contact between carbon and steel (due to the potential of galvanic corrosion).

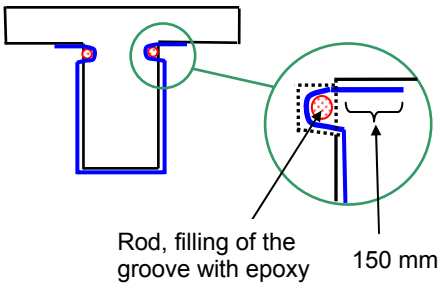


Fig. 7.6

- Minimum permissible radii at corners of rectangular cross sections are in the order of 20 mm for carbon or glass fibers and 10 mm for aramid fibers.

- Shear strengthening of columns between partial height infill walls should be done along the full column height, not just in the free part (Fig. 7.7).

Fig. 7.7 Shear strengthening of column between partial height infill walls.

- Full wrapping of columns with several pieces of FRP along the height should be done with the lap joints in different sides (Fig. 7.8).

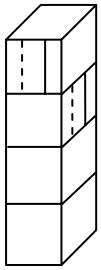


Fig. 7.8

7.2.3 Confinement

- Rounding of the corners in columns should be done at the maximum possible radius (typically determined by the concrete cover).
- Overlapping of the jacket's ends in rectangular cross sections (Fig. 7.9) should be such that fracture of the FRP would occur prior to debonding. Typical minimum lap lengths are in the order of 200 mm for carbon fiber sheets with a nominal thickness about 0.12-0.14 mm.

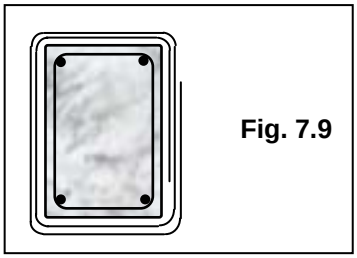


Fig. 7.9

- The maximum number of superimposed layers should be in the order of 15 or according to the material supplier's recommendation.
- When jacketing is applied at column ends for ductility, a 15 mm gap is recommended to allow for unrestraint rotation of the end cross section as well as to prevent damage of the FRP in compression (Fig. 7.10).

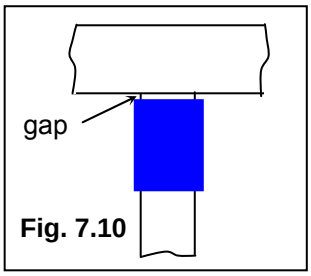


Fig. 7.10

- Concerning the application of FRP on rectangular columns or pier walls with large aspect ratio, the FRP does not actually confine the internal concrete structure if just applied to the surface. In order to achieve confinement, the jacket need to be constrained on both sides along the length through the use of dowels or bolts or spike anchors (Fig. 7.11) that anchor the jacket to the existing structure, thereby

creating shorter distances. Spike anchors provide a low cost solution, which has been tested with very good results for the attachment of FRP jackets at the reentrant corners of L-shaped cross section columns, Fig. 7.12 (Karantzikis et al. 2005).

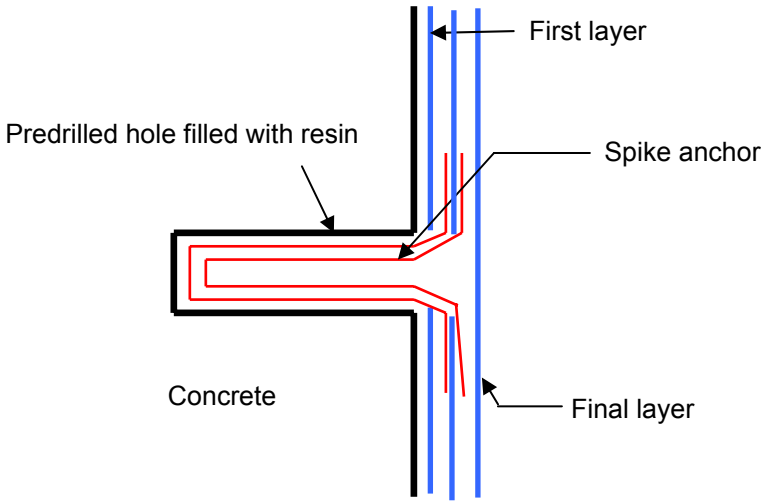


Fig. 7.11 FRP anchorage using spike anchor.

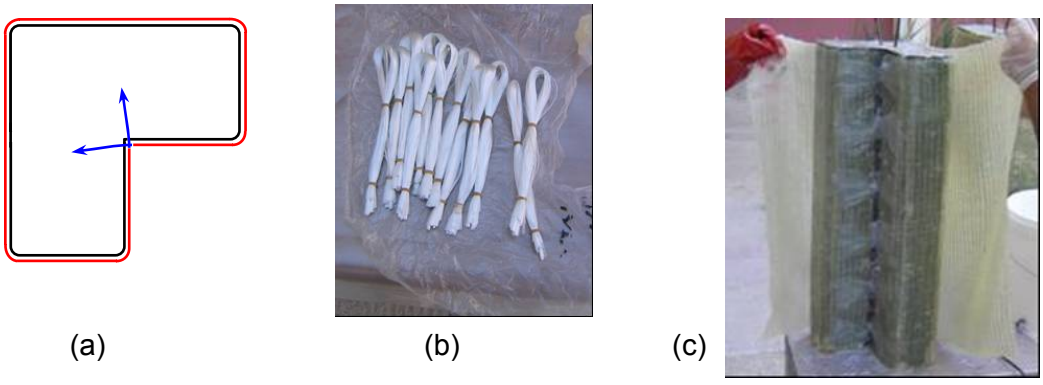


Fig. 7.12 Fixing the jacket at reentrant corner: (a) typical configuration, (b) spike anchors, (c) photograph of anchors at reentrant corner.

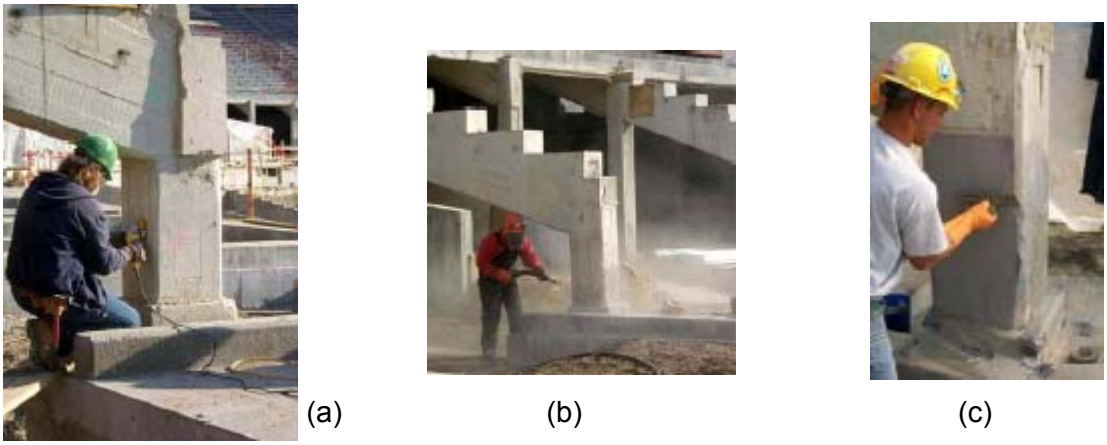
- As in the case of columns strengthened in shear, full wrapping with several pieces of FRP along the height should be done with the lap joints in different sides (Fig. 7.8).
- When jackets are provided to prevent lap-splice failures (e.g. at the bottom of columns), the FRP should extend at a height equal to at least 2/3 of the lap splice.

7.3 Practical execution

FRP materials used in strengthening and/or seismic retrofitting are typically in the form of (a) 1.0-1.5 mm thick and 50-100 mm wide strips made of carbon fibers, or (b) sheets with a nominal thickness of 0.1-0.6 mm made of carbon, glass and (more rarely)

aramid fibers. Bonding on concrete surfaces is achieved with two-part epoxy adhesives. Details about specific systems as far as material properties and practical execution are concerned are given by the supplier of the strengthening system. In this section we provide general rules, applicable to most of the commercially available systems. More details may be found in JBDPA (1999), *fib* bulletin 14 (2001) and ACI 440.2R-02 (2002).

- The concrete should be sound and free from serious imperfections (e.g. cavities, wide cracks, protrusions), roughened (e.g. by means of sand blasting or water jet blasting) and made laitance and contamination free. Surface moisture in excess of 4% requires the use of special resins. Typical surface preparation steps are given in Fig. 7.13.



(a) (b) (c)

Fig. 7.13 Surface preparation: (a) Grinding, (b) cleaning και (c) leveling.

- Use of prefabricated strips requires a minimum substrate tensile strength equal to approximately 1.5 N/mm^2 (measured in-situ through pull-off testing, Fig. 7.14).

Fig. 7.14 In-situ testing of substrate strength.

- Selection of the appropriate resin should be made on the basis of in-situ temperature and humidity requirements. Application of resins at very low temperatures may require local heating.

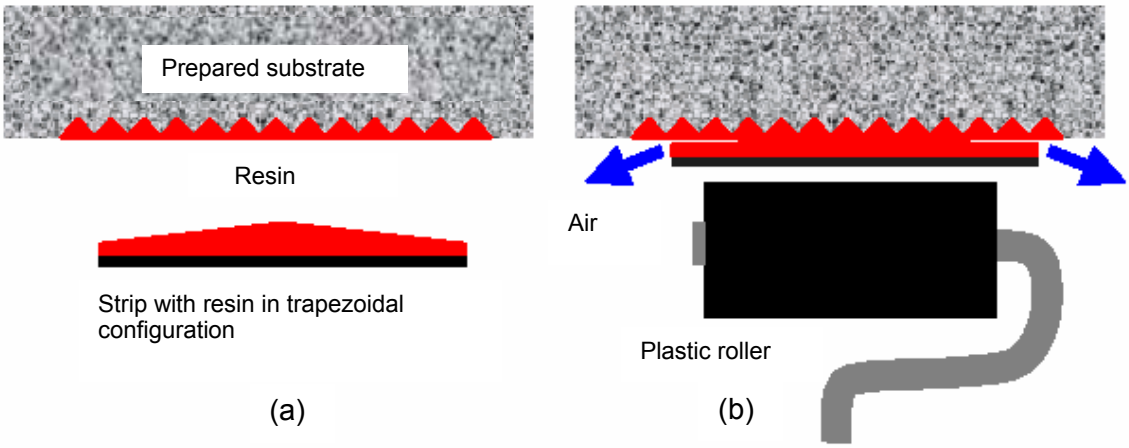


Fig. 7.15 (a) Application of resin on concrete and FRP, (b) application of pressure during rolling.

Resin application on strip.

Placement of strip.

Use of roller.

Removal of excess resin.

Fig. 7.16 Steps for the application of strips.

- FRP strips should be cut to proper size using an electric or manual saw. Depending on the type of strips, cleaning (e.g. with acetone) or removal of a surface veil may be required prior to bonding. Handling of strips by workers should be performed with care (the use of gloves is strongly recommended).

- Bonding of strips should be followed by the application of pressure using a plastic roller, to remove entrapped air and excess resin (Fig. 7.15-7.16).
- Sheets should be applied with special care to ensure that wrinkles are avoided and that the fibers are as straight as practically possible. Impregnation of sheets with resin is achieved using a plastic roller (Fig. 7.17)

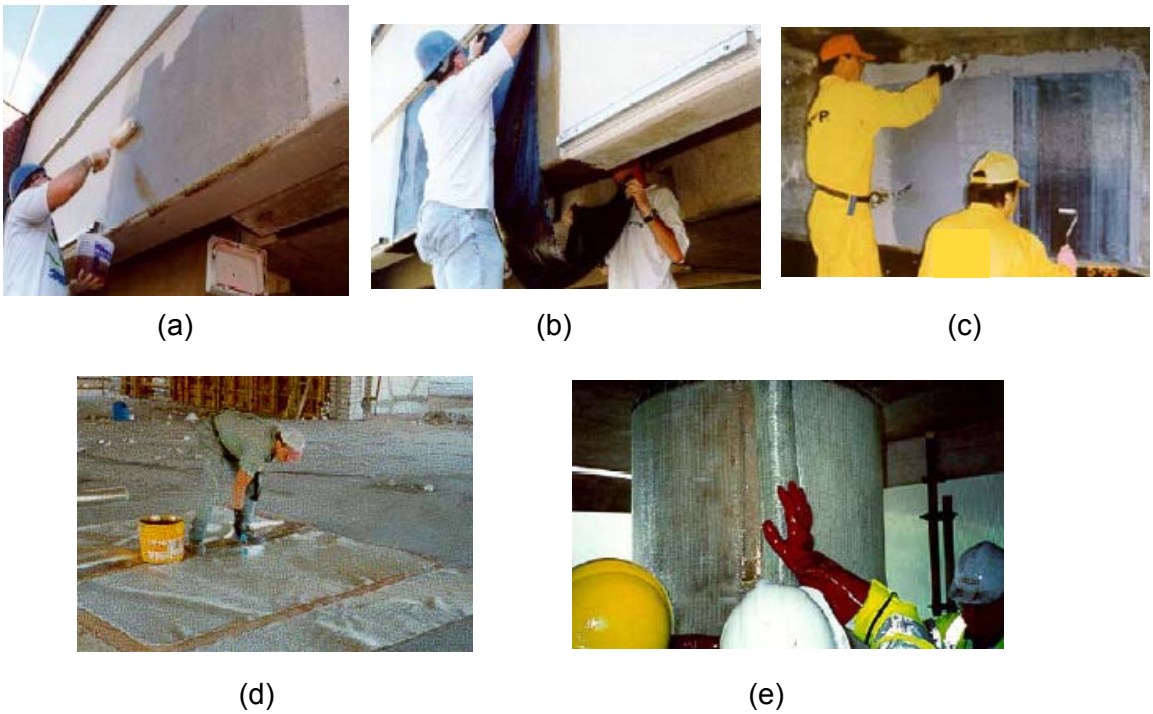


Fig. 7.17 In-situ impregnation of sheet: (a) Prime, (b) placement of first layer of sheet, (c) impregnation of sheet on concrete. (d) Pre-impregnation of sheet and (e) application of pre-impregnated sheet.

- The average thickness of resin layer between strips and the concrete substrate should be in the order of 1.5 mm. The resin used to impregnate sheets must have an appropriate viscosity and used at the proper quantity, to ensure full impregnation without entrapped air.
- Application of mortar plastering directly on the FRP can be made possible by providing a rough surface through the application of a certain quantity of sand (in the order of 1 kg/m^2) directly on the last layer of resin prior to its hardening.
- Last, but certainly not least, the FRP strengthening system should be applied by **properly trained and qualified personnel**.