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STRENGTHENING TECHNIQUES OF RC COLUMNS USING FIBRE REINFORCED POLYMERIC MATERIALS

BY

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Abstract. Fibre reinforced composite materials are becoming more frequently used in civil engineering structures. One of the most practical applications of these new materials concerns the strengthening of reinforced concrete columns by means of confinement with fibre composite sheets. In the literature, various theoretical models have been proposed to describe the behaviour of confined concrete columns. The principal advantages of this technique are the high strength-to-weight ratio, good fatigue properties, non-corroding characteristics of the fibre reinforced polymers (FRP), and the facility of its application. The maximum efficiency of confining systems using FRP materials is reached in case of columns with circular cross-section and is explained by the fact that the entire section of the column is involved into the confinement effect. Rectangular confining reinforcement is less efficient as the confinement action is mostly located at the corners This paper reveals the most utilized techniques of performing composite confining systems for reinforced concrete columns, with their advantages and also disadvantages.

Key words: RC columns; fibre reinforced polymeric composites (FRP); strengthening systems.

1. Introduction

Over the years, engineers have used different methods and techniques to retrofit existing structures by providing external confining stresses. For the past few years, the concept of jacketing has been investigated to provide such forces. Externally applied jackets have been used as a reinforcement to contain concrete for different reasons. Engineers have used traditional materials such as wood, steel, and concrete to confine and improve the structural behavior of concrete members [7].

Section enlargement is one of the methods used in retrofitting concrete members. Enlargement is the placement of reinforced concrete jacket around the existing structural member to achieve the desired section properties and performance. The main disadvantages of such system are the increase in the column size obtained after the jacket is constructed and the need to construct a new formwork.

Steel jacketing has been proven to be an effective technique to enhance the seismic performance of old bridge columns. The steel jacket is manufactured in two shell pieces and welded in the field around the column. However, this method requires difficult welding work and, in a long term, the potential problem of corrosion remains unsolved [7].

Interesting in the use of flexible fiber reinforced plastic (FRP) sheets for the external wrapping of concrete compressed members is today a very popular theme, especially as regards estimating the effectiveness of this reinforcing technique in increasing the strength and ductility of members in seismic areas [1].

Several advantages are observed in using FRP wraps compared to the most common other techniques based on the use of steel reinforcements such as: the high-mechanical properties of the material (tensile strength and elasticity modulus) compared with its lightness; its insensitivity to corrosion; the ease of applying the reinforcing material, etc. [1].

2. FRP Confining Systems in Case of RC Columns

Confinement is generally applied to members in compression, with the aim of enhancing their load carrying capacity or, in cases of seismic upgrading, to increase their ductility. Advanced FRP composite materials have only recently been recognized as reliable confinement devices for reinforced concrete elements. FRP, as opposed to steel that applies a constant confining pressure after yield, has an elastic behavior up to failure and therefore exerts its (passive) confining action on concrete specimens under axial load in a different way with respect to steel. In Fig. 1 it can be seen that, at a certain value of the normalized axial concrete strain, the steel reaches yielding and then, from that point on, it exerts a constant lateral (confining) pressure, while FRP exerts a continuously increasing confining action [3], [8].

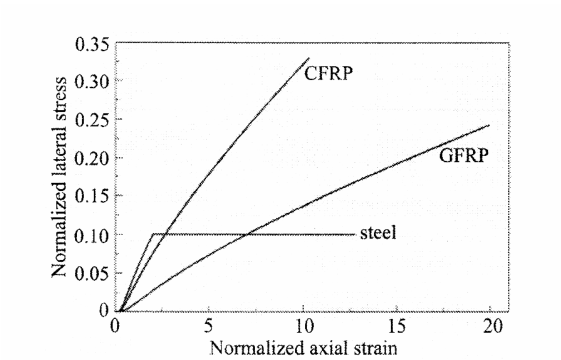

Fig. 1 – Comparison of confinement actions of steel and FRP materials.

Utilizing composite systems for confinement of concrete, a transfer of tensile stresses from concrete to the composite system is realized. The confining system changes the characteristic loading – strain behavior of concrete applying it a confining pressure. The maximum efficiency of confining systems using FRP materials is reached in case of columns with circular cross-section and is explained by the fact that the entire section of the column is involved into the confinement effect. The confining pressure is uniformly distributed on the entire cross-section of the element. In case of columns with noncircular cross-section only a part of it is subjected to the confining effect, and that part is known as the confined area or active area (Fig. 2) [5].

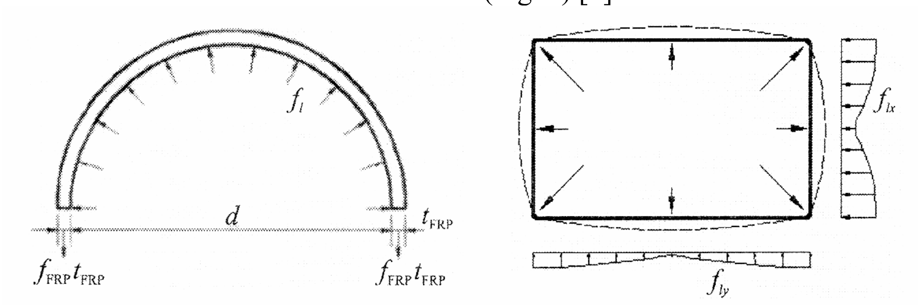

Fig. 2 – Distribution of confining pressure in case of columns with circular and rectangular cross-section; f_l – the confining pressure; f_{FRP} – FRP longitudinal tensile strength; d – the diameter of the RC column cross-section; t_{FRP} – thickness of the composite material; $f_{lx,y}$ – the confining pressures given by x- and y-directions.

The main objectives of confinement are: (i) to prevent the concrete cover from spalling, (ii) to provide lateral support to the longitudinal reinforcement and (iii) to enhance concrete strength and deformation capacities. In the case of circular columns these goals can be achieved by applying external FRP jackets, either continuously all over the surface or discontinuously as strips. In the case of rectangular columns, the confinement can be provided with rectangular-shaped reinforcement, with corners rounded before application (the

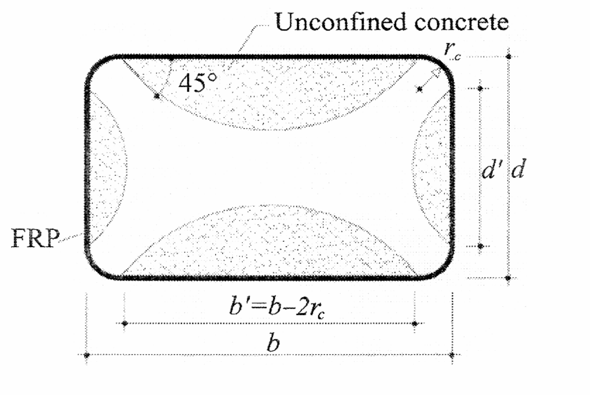

Fig. 3 – Effectively confined core for non-circular sections.

radius is about 15…25 mm, depending on the specifications given by the FRP jacket supplier). Rectangular confining reinforcement is less efficient as the confinement action is mostly located at the corners and a significant jacket thickness needs to be used between corners to restrain lateral dilation and column bar buckling. An alternative approach is to enclose the rectangular column within an externally cast circular or oval shape that provides the appropriate shape for the jacket (Fig. 3) [8].

3. Confining Techniques

Today there are several types of FRP strengthening systems namely
a) wet lay-up systems;
b) systems based on prefabricated elements;
c) special automated wrapping systems.

a) *Wet lay-up process* represents the most commonly used technique, in which unidirectional fibre sheets or woven fabric sheets are impregnated with resins and wrapped around columns, with the main fibres oriented in the hoop direction [2]. Installation on the concrete surface requires saturating resin, usually after a primer has been applied. Two different processes can be used to apply the fabric [9]: (i) the fabric can be applied directly into the resin which has been applied uniformly onto the concrete surface, (ii) the fabric can be impregnated with the resin in a saturator machine and then applied wet to the sealed substrate.

The wrapping can be realized continuously around the entire element or partially, using sheets of FRP disposed in spiral or in distinct sections. There can be applied variable number of layers (from same material or distinct ones), obtaining different thicknesses of the confining layer, depending on the required element strength (Fig. 4) [4].

Fig. 4 – Wet lay-up confining system.

b) When *prefabricated FRP jackets* are used, the jackets are fabricated in half circles or half rectangles and circles with a slit or in continuous rolls, so that they can be opened up and placed around columns (Fig. 5). This can be considered as technical most elaborated system, but the major problems emerge in the closure area of the composite layer because of insufficient overlapping [2].

Fig. 5 – Confining system based on prefabricated FRP elements.

c) *The FRP automated wrapping* technique through winding of tow or tape was first developed in Japan in the early 90s and a little later in the USA. The technique, shown in Fig. 6, involves continuous winding of wet fibres under a slight angle around columns by means of a robot. Key advantage of the technique, apart from good quality control, is the rapid installation [9].

Fig. 6 – Automated RC column wrapping.

Choosing the confining technique depends on the following factors:
a) the importance and the volume of the strengthening work;

b) the type of composite materials used;
c) the working gang experience;
d) working conditions and the period of time available to perform the job;
e) the financial availability.

Table 1 presents the main advantages and disadvantages of the three execution methods for confining systems with composite materials [6].

Table 1
Advantages and Disadvantages of the Methods Used for Confining with Composite Systems

	Advantages	Disadvantages
Wet lay-up method	a) workability to a large type and shapes of columns; b) easy to handle.	a) reduced quality control; b) high volume of work on site.
Automated method	a) high quality control; b) reduced volume of work on site.	a) workability to a reduced shapes of columns; b) special equipments required.
Confining with prefabricated elements	a) the best quality control; b) reduced volume of work on site.	a) workability to a reduced shapes of columns; b) high costs.

These systems correspond to several manufacturers and suppliers and are based on different configurations, types of fibres, adhesives, etc. Practical execution and application conditions, for example cleaness and temperature, are very important in achieving a good bond. A dirty surface will never provide a good bond. The adhesives undergo a chemical process during hardening that needs a temperature above 10°C to start. If the temperature drops, the hardening process delays.

4. Conclusions

The most utilized techniques of performing composite confining systems for reinforced concrete columns are: wet lay-up method, automated method and the method based on using prefabricated elements.

For developing efficient composite confining systems it is required to respect the technological steps that lead to a corresponding transfer of stresses from concrete to the composite membrane. These steps include: priming of the concrete substrate, of the application surface, execution of the resin mixture, application of the composite system and of the protection layers.

The confining pressure develops on a so called confined area and the size of it determines the efficiency of the confining system. The most efficient can be considered to be the columns with circular cross-section, where the confined area represents the entire transversal cross-section of the column.

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TEHNICI DE CONSOLIDARE A STÂLPILOR DIN BETON ARMAT UTILIZÂND MATERIALE POLIMERICE ARMATE CU FIBRE

(Rezumat)

Utilizarea materialelor compozite armate cu fibre la structurile inginereşti a devenit uzuală în ultimii ani. O aplicaţie frecventă a acestor materiale inovative o constituie consolidarea stâlpilor din beton armat prin confinare cu fâşii din fibre compozite. În literatura de specialitate au fost propuse diferite modele teoretice de analiză a comportării stâlpilor din beton confinați. Avantajele principale ale acestei tehnici sunt date de raportul ridicat dintre rezistență şi greutate, comportare bună la oboseală, caracteristici non-corozive date de polimerii cu fibre şi uşurință în aplicare. Eficiența maximă a sistemelor de confinare utilizând materiale polimerice armate cu fibre este realizată în cazul stâlpilor cu secțiune circulară, explicația dată de faptul că întreaga secțiune de beton este implicată în efectul confinării. Confinarea rectangulară este mai puțin eficientă întrucât acțiunea de confinare este localizată în special în zona colțurilor. Această lucrare prezintă cele mai utilizate tehnici de realizare a sistemelor de confinare cu materiale compozite în cazul stâlpilor din beton armat, cu avantaje dar şi cu dezavantaje.