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Confinement of FRP-Strengthened Columns

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Abstract

In recent decades, buildings have suffered damage due to natural disasters such as earthquakes, floods, and heavy snowfalls. One of the effective methods for reducing damage is the strengthening, rehabilitation, and retrofitting of existing structures. In this context, the use of Fiber Reinforced Polymer (FRP) composites, particularly in concrete structures, has gained significant popularity. The growing use of these materials can be attributed to their distinct advantages over traditional materials such as steel.
Parameters such as the orientation, alignment, and number of FRP layers have a considerable impact on the behavior of strengthened columns and are frequently investigated through analytical and experimental studies. The results indicate that increasing the number of FRP layers leads to an improvement in ultimate strength, ultimate displacement, and ductility. Moreover, the layer arrangement of the FRP sheets has a distinct influence on the behavior of reinforced concrete columns.

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Introduction

Composite materials refer to materials composed of two or more constituent substances combined together, where each constituent performs a distinct function. Provided that no chemical reaction occurs between them, the resulting composite material exhibits properties significantly different from those of its individual components.

FRP composites are produced by embedding continuous fibers into an adhesive paste or resin[2] matrix (Figure 1). The fibers play the primary role in determining the mechanical strength and properties of the composite material, while the resin's function is to bond the fibers together and protect them against environmental factors (Karbhari and Gao[3], 1997).

Figure 1. Components of FRP composites (Challal and Shahawy, 2000)

FRP composites are categorized based on the type of commonly used fibers—carbon, glass, and aramid—into three groups: CFRP[4] (Carbon Fiber Reinforced Polymer), GFRP[5] (Glass Fiber Reinforced Polymer), and AFRP[6] (Aramid Fiber Reinforced Polymer) (Saccioglu[7] and Haman, 1995).

When transverse FRP composites are used in column strengthening such that the fibers are oriented horizontally, the column becomes confined by the composite. When a compressive load is applied to a concrete cylinder, in addition to axial strain, lateral strain also develops due to the Poisson effect (Pham et al., 2003).

When concrete reaches its tensile strength, cracks parallel to the applied force appear, and the concrete disintegrates. Applying compressive stress perpendicular to the direction of the formed cracks prevents their propagation and increases the concrete's strength. Confinement is the prevention of radial dilation of concrete by applying lateral pressure. (Challal & Shahawy, 2000)

1. Resin
2. karbhari V.M and Gao,Y
4 . Chaallal, O. and Shahawy, M
5 Carbon Fiber Reinforced Polymer
6 Glass Fiber Reinforced Polymer
7 Aramid Fiber Reinforced Polymer
7. Saatcioglu, M., Salamat, A. H. and Razvi, S. R
8. Fam, A., Flisak, B. and Rizkalla, S

Extensive research has been conducted on the confinement of reinforced concrete columns, including:

In 1998, a group of researchers investigated the effect of cross-sectional shape, aspect ratio (length to diameter), and chemical and mechanical bond on the behavior of GFRP-confined columns under axial compressive load. After conducting experiments, these researchers concluded that square sections are not affected by confinement to the same extent as circular sections. This is because, in circular sections, the confining pressure is uniform, whereas in square sections, this pressure varies from its maximum value at the corners to its minimum value at the middle of the sides. (Esfahani & Kianoush, 2004)

Also, in 2001, a number of researchers examined the effectiveness of FRP (Fiber Reinforced Polymer) confinement for rectangular reinforced concrete columns. They considered the effects of parameters such as fiber type, layer thickness, section aspect ratio, and corner radius on axial strength and strain. The test results showed that increasing the sharpness of the corner and increasing the aspect ratio reduce the ultimate capacity of the column. (Saman et al., 1998)

In 2012, another group of researchers studied the effect of column size on confinement by CFRP (Carbon Fiber Reinforced Polymer). In this study, 37 concrete columns with different diameters and an aspect ratio of height to diameter equal to 2 were confined using 1, 2, and 3 layers of FRP and subjected to axial loading. They also used finite element analysis to examine the effect of column size in this study.

They used it. The research results show that, at the same confinement ratio, the size of the confined column does not have a significant effect on its compressive strength and ultimate strain. (Kool and Blalby, 2004)

Numerical Analysis Review

Analytical studies on concrete columns require a significant amount of time and the use of high-capacity computers. In this section, to verify the accuracy of the modeling method, several experimental tests conducted on 150×300 mm cylindrical specimens confined with FRP fibers—previously studied by Xia & Wu (Triwliot et al., 2004)—are simulated. The constructed columns were wrapped with one, two, and three layers of FRP. The dimensions of the samples in the numerical modeling match those of the laboratory specimens. The plastic behavior of concrete under compression is modeled based on the Hognestad curve, and the effect of cracking in the tensile region is also considered. Figure 2 presents both the experimental and numerical results. The graphs demonstrate that the ABAQUS software is highly capable of accurately modeling the behavior of FRP-confined concrete columns.

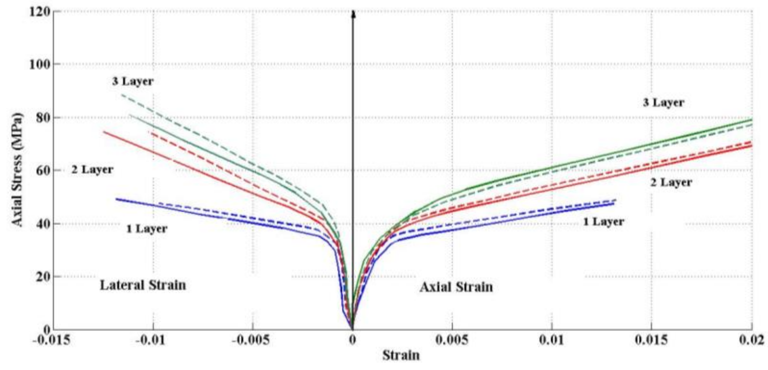

Figure 2. Comparison of Finite Element Software Results and Experimental Data (ibid., 2004)

3. Column Specifications

The column under investigation has a diameter of 150 mm and a height of 300 mm, with a compressive strength of 44 MPa. The thickness of the FRP used is 0.381 mm, and its elastic modulus is $1.05\times10^5\,(MPa)$ [8]

Numerical Analysis Results

The stress–strain curves of the modeled specimens obtained from the ABAQUS software for the studied samples are as follows:

Figure 3 presents the stress–strain curve of a concrete column with a compressive strength of 44 MPa, confined at the mid-height with one and two layers of FRP fibers.

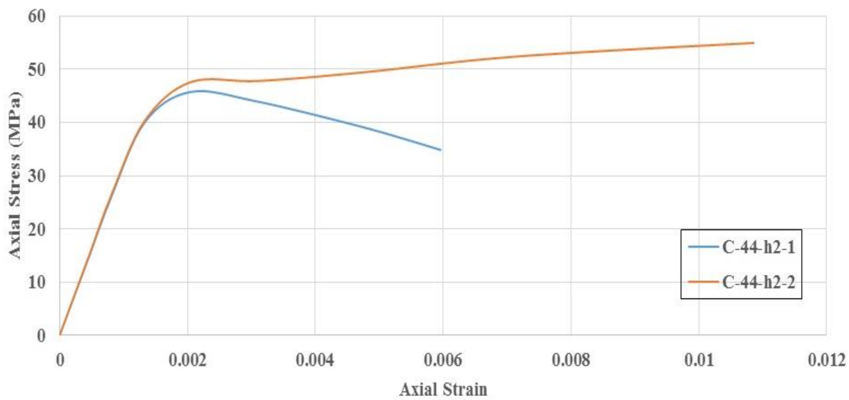

Figure 3. Stress–Strain Curve of a Concrete Column with a Compressive Strength of 44 MPa

Figure 4 illustrates the stress–strain curve of a concrete column with a compressive strength of 44 MPa, confined with one and two layers of FRP fibers in the middle third region of the column.

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1. Cole, C. and Belarbi, A

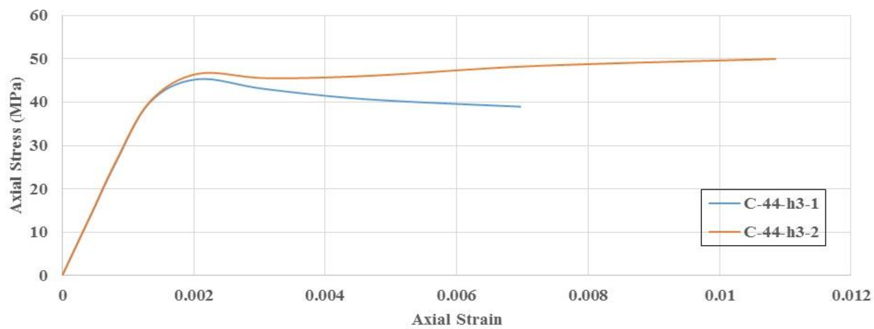

Figure 4. Analysis results of C-44-h3-1 and C-44-h3-2

In Figure 5, the stress-strain curve of a concrete column with a compressive strength of 44 MPa, confined with one and two layers of FRP fibers in the form of spiral strips with a width equal to one-fifth of the column height, is presented.

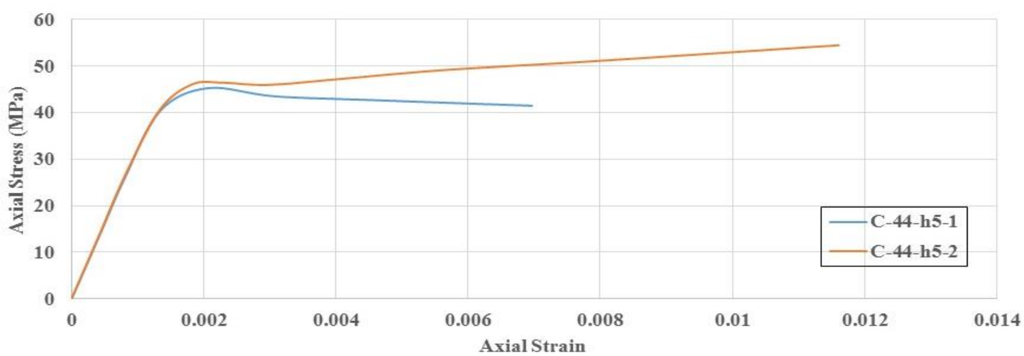

Figure 5. Analysis Results of C-44-h5-1 and C-44-h5-2

As observed in the above graphs, the behavior of columns strengthened with two layers of FRP differs from that of columns confined with a single layer of FRP.

Conclusion

Concrete columns with different FRP configurations and varying numbers of layers were strengthened and examined. Considering different FRP arrangements results in significant changes in the behavior of the concrete columns; these changes are interpreted below through tables and graphs:

The use of FRP fibers induces confinement in concrete columns, which in turn increases the load-bearing capacity along with enhanced ductility of the columns.

Increasing the number of FRP layers in all specimens leads to improvements in both ductility and strength. Additionally, the maximum axial strain increases, while the lateral strain in the studied columns decreases correspondingly.

Comparing sample C-44-h2-2 with sample C-44-h5-2 reveals that despite the reduced amount of FRP fibers in the middle region of C-44-h5-2 specimens, a slight decrease in strength occurs even with the use of a greater total amount of FRP. This can be attributed to better confinement and reduced cracking in the middle region of C-44-h2-2 samples. However, the application of FRP strips at the top and bottom of the column in C-44-h5-2 samples effectively controls stress concentration at the supports. Therefore, employing FRP strips at the supports combined with adequate confinement in the middle region can be considered the optimal strategy for strengthening concrete columns.

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