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Effects of wrap thickness and ply configuration on composite-confined concrete cylinders

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Abstract

The behavior of small-scale fiber reinforced polymer (FRP) wrapped concrete cylinders under uniaxial compressive loading was investigated through nonlinear finite element analysis. Two parameters were considered for this numerical study: the FRP wrap thickness, and the ply configuration. Performances of numerical models with "hoop-angle-hoop" and "angle-hoop-angle" ply configurations were compared, where the terms "hoop" and "angle" indicate that wraps were oriented at an angle of 0° and 45° in reference to circumferential direction, respectively. The finite element analysis results showed substantial increase in the axial compressive strength and ductility of the FRP confined concrete cylinders as compared to the unconfined ones. The cylinders with "hoop-angle-hoop" ply configuration in general exhibited higher axial stress and strain capacities as compared to the cylinders with the "angle-hoop-angle" ply configuration. The increase in wrap thickness also resulted in enhancement of axial strength and ductility of the concrete cylinders.

Keywords: Columns; Concrete; Fibers; Composite wrap; Uniaxial compression; Strength; Ductility; Ply angle; Wrap thickness

1. Introduction

Although a concrete-filled steel tube is an effective retrofit technique and has been used widely in practice, fiber composite jackets have recently shown great potential as a desirable alternative to steel jackets for retrofitting as well as new construction since fiber composite materials are lightweight, noncorrosive, and exhibit high tensile strength [1–9]. The composite jacket provides enhancement in compressive strength and ductility due to confining the concrete core.

Studies performed on fiber reinforced polymer (FRP) confined concrete columns are more infrequent and limited compared to extensively available database on FRP-strengthened concrete beams. Many of the studies on FRP-confined concrete columns involve evaluation of experimental results with available confinement models in the literature [1,2] while others focus on prediction of bilinear stress–strain response of FRP-confined concrete columns under uniaxial compression: employment of analytical models and subsequent validation with experiments of their own or other researchers [3–5] is widely adopted. As an on-going deficiency in the literature, parametric studies related to the effect of "hoop-angle-hoop" and "angle-hoop-angle" ply configurations have not been taken into account in most of the studies of FRP-jacketed columns reported. On the other hand, limited investigations suggest this parameter influences the strength and ductility of FRP-wrapped columns subjected to the axial load [7]. In presence of the perceived deficiency in current literature and significance of the issue, this research indeed explores the effects of ply angle and ply stacking sequence combined with wrap thickness on FRP-confined short columns through nonlinear finite element analysis: the expectation is to develop a better understanding and consequently to be able to leverage this understanding to fine-tune these parameters in design. A literature survey of significant research studies relevant to this research thrust will be presented next.

A number of studies on FRP-confined concrete columns subjected to uniaxial compression, where the wrap angle orientation was 0° with respect to circumferential direction, appeared in the recent literature. Nanni and Bradford [1] tested 152.5×305 mm (6×12 in.) FRP-confined concrete cylinders to verify the validity of

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existing analytical models. Their experimental results indicated that the jacket increased the ductility and strength significantly and the analytical models were accurate for the prediction of strength, but underestimated the ultimate strain of FRP-confined columns. Saafi et al. [4] tested short concrete columns confined with FRP tubes under uniaxial compressive load to investigate the effects of FRP jacket thickness as well as fiber type and concrete strength. Significant improvement in strength, ductility, and energy capacity was reported and the axial strain of confined concrete increased as the jacket thickness increased. Parvin and Wang [6] performed experimental and numerical analysis of FRP-jacketed square concrete columns under eccentric loading, where the effects of various eccentricities and FRP jacket thickness were investigated. The results showed that strength and ductility of concrete FRP-jacketed columns under eccentric loading can greatly increase and that the strain gradient decreases the retrofit efficiency of the FRP jacket for concrete columns. Additionally, similar to short columns subjected to concentric axial load, the strength and ductility of the eccentrically loaded columns increased as the jacket thickness increased. Although this study involved the effects of the wrap and its thickness on short columns it was limited to 0° ply orientation configuration.

A number of researchers employed a ply orientation different than just 0° with respect to circumferential direction in FRP-confined concrete columns while not necessarily studying variations in ply angle and ply stacking sequence. Mirmiran and Shahawy [2] conducted experiments on axially loaded 152.5×305 mm (6×12 in.) concrete-filled FRP tubes made of unidirectional E-glass fibers at ±15° winding angle. Various jacket thicknesses of 6, 10, and 14 plies were examined, while winding angle was fixed. Their findings indicated that, as the jacket thickness increased, the strength and ductility increased as well. However, their study was concentrated on one winding angle configuration (±15° winding angle) with no further discussion on this parameter. Rochette and Labossiere [7] axially tested the effect of wrap thickness and cross-section shape of short column on its strength (circular, square, and rectangular). The wraps had 0° angle orientation with horizontal axis with the exception of one square specimen being wrapped with [±15°/0°] "angle-hoop" configuration. Their results indicated that confinement enhanced the strength of axially loaded short columns as much as 92%. The variation of number of plies on square columns wrapped with carbon or aramid improved the strength and ductility as the number of plies increased. The column with "angle-hoop" configuration exhibited a peculiar behavior. Although the maximum strength of five-layer "angle-hoop" confinement increased as compared to four-layer circumferential confinement, its ductility decreased: the number of layers were chosen such that the overall confinement stiffness of five-layers "angle-hoop" would be approximately equivalent to four-layer circumferential confinement. They concluded that the effect of "angle-hoop" wrap as a candidate for obtaining more strength and ductility should be investigated. Their study on the ply orientation was limited to one specimen and one "angle-hoop" configuration.

Pessiki et al. [8] performed experiments on small-scale square and circular plain concrete specimens as well as large-scale square and circular reinforced concrete FRP-jacketed columns under axial load. The FRP jackets were made of (a) 0°/±45° multidirectional E-glass fiber reinforced polymer (GFRP) jackets E-glass fabric with 50% of its fibers oriented at 0° angle with respect to circumferential direction and 25% of fibers oriented at each of ±45°), (b) 0° unidirectional GFRP jackets, and (c) 0° unidirectional carbon fiber reinforced polymer (CFRP) jackets. The compressive strength increased by 128% for small-scale circular specimens with one-ply 0°/±45° GFRP jacket and 244% for circular specimens with two-ply 0° CFRP jackets. Additionally, as compared to unjacketed specimens, axial strains at peak stress have increased approximately seven times. Their investigation on fiber orientation was limited to a single configuration for fiber orientation at 0°/±45°.

It would be a reasonable assessment to state that practically all studies presented thus far have not adequately looked at the effects of angle and hoop plies and their staking sequence such as "hoop-angle-hoop" and "angle-hoop-angle" combined with various wrap thicknesses. Some have just investigated one "angle" wrap configuration, while others performed limited studies on "hoop-angle" or "angle-hoop" ply configurations combined with various thicknesses without any concentration on stacking sequence effect.

When fibers are oriented with an angle with respect to circumferential direction, they provide effective modulus and strength in both axial and hoop directions, and this may eliminate the use of conventional steel reinforcement from the column altogether. Also, since shear cracks usually happen at ±45° angle, the ±45° wrap angle combination will possibly ensure reinforcement perpendicular to the shear crack and suppress shear failure. For instance, in the case of column of a joint subject to both axial and transverse loadings, the shear capacity and/or flexural capacity might increase when using ±45° ply for the wrap [9]. Furthermore, the axial strength capacity might increase due to existence of "hoop-angle-hoop" plies and their confinement effect, while the rate of increase for each capacity might vary.

The objective of our study is to characterize the increase in stress–strain response of FRP-confined concrete cylinders due to the jacket thickness and staking sequence of plies with various angles in the jacket. The MSCMARC™ 2001 nonlinear finite element analysis (FEA) software will be employed for modeling and